IC 9128

Bureau of Mines Information Circular/1987

Iron Ore Availability—Market Economy Countries

A Minerals Availability Appraisal

By Judith L. Bolis and James A. Bekkala

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environment and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

Library of Congress Cataloging-in-Publication Data

Bolis, Judith L.

Iron ore availability—market economy countries.

(Information circular ; 9128)

Bibliography: p. 56

Supt. of Docs. no.: I 28.27: 9128

1. Iron ores. I. Bekkala, James A. II. Title. III. Series: Information circular (United States. Bureau of Mines) ; 9128.

~~TN295.U4~~ [TN401] 622 s [338.2'73] 86-600224

PREFACE

The Bureau of Mines is assessing the worldwide availability of selected minerals of economic significance, most of which are also critical minerals. The Bureau identifies, collects, compiles, and evaluates information on producing, developing, and explored deposits, and mineral processing plants worldwide. Objectives are to classify both domestic and foreign resources, to identify by cost evaluation those demonstrated resources that are reserves, and to prepare analyses of mineral availability.

This report is one of a continuing series of reports that analyze the availability of minerals from domestic and foreign sources. Questions about, or comments on these reports, should be addressed to Chief, Division of Minerals Availability, Bureau of Mines, 2401 E St., NW, Washington, DC 20241.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

DWT	deadweight ton[1]	MMlt/yr	million long tons per year
ft	foot	MMst	million short tons
in	inch	Mmt	million metric tons
kg	kilogram	Mmt/yr	million metric tons per year
km	kilometer	mt	metric ton[2]
lb	pound	mt/d	metric ton per day
L	liter	mt/h	metric ton per hour
L/mt	liter per metric ton	pct	percent
lt	long ton[2]	pct/yr	percent per year
ltu	long ton iron unit	st	short ton[2]
lt/yr	long ton per year	wt pct	weight percent
m	meter	yr	year
mm	millimeter	¢/(mt·km)	cents per metric ton-kilometer
MMlt	million long tons		

[1]Measured as the difference between a ship's displacement light and her displacement loaded; the carrying capacity of a ship measured in long tons (2,240 lb).
[2]1 mt = 0.98421 lt = 1.1023 st.

IRON ORE AVAILABILITY—MARKET ECONOMY COUNTRIES

A Minerals Availability Appraisal

By Judith L. Bolis[1] and James A. Bekkala[1]

ABSTRACT

The Bureau of Mines estimated the potential availability of iron ore from 129 domestic and foreign mines and deposits in 25 market economy countries. The availability of four products on a total and regional basis was determined from demonstrated resources of 75.3 billion lt.

From the resources evaluated there are a total of 18.6 billion lt of sinter fines, 4.9 billion lt of lump ore, 14.7 billion lt of pellets, and 820 MMlt of pellet feed potentially available at a 15-pct DCFROR, f.o.b. port. On a regional basis, at or below a total cost of $0.26 per iron unit there are 1.7 billion lt, 2.8 billion lt, and 186 MMlt of sinter fines potentially available from Brazil, Australia, and Africa, respectively. There are 825 MMlt of lump ore from Brazil and 1.4 billion lt from Australia potentially available at or below a total cost of $0.24 per iron unit. There are 2.1 billion lt of pellets potentially available from the United States at or below a total cost of $0.80 per iron unit, while 442 MMlt are potentially available in Brazil at or below $0.38 per iron unit. South America has 208 MMlt of pellet feed potentially available at or below a total cost of $0.28 per iron unit.

While the resources of iron ore are more than adequate to satisfy demand, the future of the iron ore industry is very dependent upon changes in the world economy, and on the domestic scene, changes in the domestic steel industry and steel imports.

[1]Mining engineer, Minerals Availability Field Office, Bureau of Mines, Denver, CO.

INTRODUCTION

Iron is the fourth most abundant element, composing almost 5 wt pct of the earth's crust. It is estimated that world resources of iron ore exceed 800 billion lt of crude ore containing more than 232 billion lt Fe (*1*).[2] The purpose of this report is to identify and define the demonstrated iron ore resources in market economy countries (MEC's)[3] and evaluate the potential production in its various forms from these resources. The data furnished for this study came from 129 operating mines and known deposits located in 25 MEC's.

In a study of this nature it was not possible, nor was it intended, to conduct a comprehensive worldwide evaluation of such an immense resource within the constraints of time and budget allocated. Therefore, the scope of this study involved the evaluation of technical and economic data from operating mines, past producers, and developing and explored deposits in the major MEC's.

The procedure followed for this evaluation was to identify recoverable resources and the engineering and economic parameters that would affect production from the deposits selected for evaluation. Capital investments and operating costs (direct and indirect) for the appropriate mining and beneficiation methods were estimated, transportation costs were assessed, and a cost evaluation for each deposit was performed. Finally, the individual deposit evaluations were aggregated to show the potential iron ore products available at various cost levels.

Iron ore is the source of primary iron for the iron and steel industries that consume about 98 pct of all iron ore production. Iron ore is used almost exclusively for the production of pig iron and is the main ingredient of the blast-furnace charge. Iron ore is marketed as a number of different products, and the product forms are based largely on physical characteristics. A plethora of brand names and physical and chemical specifications exist for iron ore products. The iron ore products presented in this study are lump ore, sinter fines, pellet feed, and pellets.

The availability curves that have been developed for this study show total long tons of iron ore products available at a specific total cost per iron unit. The iron unit, which refers to the metal content of the ore, is widely used in the industry as a basis for determining prices, shipping costs, etc. An iron unit may be defined as 0.01 lt (1.0 pct) of contained iron; i.e., 22.4 lb (since 1 lt = 2,240 lb). An iron ore of 65 pct Fe contains 65 iron ore units per long ton of ore. Therefore, the ores are priced on an iron unit basis.

Several tonnage units are used throughout the report. The domestic industry uses long tons (lt), while the foreign industry frequently uses metric tons (mt). Discussion of foreign mines and deposits in the country availability section is reported in metric tons, except for the results from the availability study. Long tons (lt), which are equivalent to gross tons, and short tons (st) appear in the report in tables and text as information from other sources.

ACKNOWLEDGMENTS

The authors wish to thank Frederick L. Klinger, formerly iron ore commodity specialist, Bureau of Mines, Division of Ferrous Metals, and Sylvia J. Arbelbide, formerly of the Minerals Availability Field Office, for their assistance.

Production and cost data for domestic deposits were developed at Bureau of Mines Field Operations Centers. The Bureau's Minerals Availability Field Office, Denver, CO, developed foreign production and cost data, performed the engineering and economic evaluations on the properties, and prepared this report.

COMMODITY OVERVIEW

STATE OF THE INDUSTRY

Annual world iron ore production usually exceeds 800 MMlt, of which nearly 57 pct is produced in MEC's. The trends of iron ore production from 1976 through 1985 are shown by country in table 1. Figures for 1984 indicate a reversal of a downward trend that began in 1980 with nearly an 8-pct increase over 1983 levels. The estimates for 1985 show the highest production levels since 1981. Five major producing MEC's accounted for 38.7 pct of 1984 world production, led by Australia and Brazil at 88.6 MMlt each, together accounting for nearly 23 pct of the world total. The United States, India, and Canada followed with 6.5, 5.1, and 4.7 pct, respectively. The U.S.S.R. accounted for nearly 31 pct of total world production. Total 1984 production in the CPEC's was 340.2 MMlt, of which nearly 31 pct (243.1 MMlt) was from the U.S.S.R.

During the period 1976-81, U.S. production accounted for about 9 pct of total world output. Production fell to 6.5 pct of world output in 1984 and to an estimated 6.0 pct in 1985 (*1*). Production increased in 1984 from 1983 levels in most countries, with the United States showing a 36-pct increase.

[2]Italic numbers in parentheses refer to items in the list of references at the end of this report.

[3]Market economy countries are defined as all countries that are not considered centrally planned economy countries (CPEC's). The CPEC's are Albania, Bulgaria, China, Cuba, Czechoslovakia, German Democratic Republic, Hungary, Kampuchea, Laos, Mongolia, North Korea, Poland, Romania, U.S.S.R., and Vietnam.

Table 1.—World iron ore production
(Million long tons)

Country	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985[e]
MEC's:										
Australia	91.8	94.6	81.9	87.6	94.0	84.6	86.4	72.8	88.6	90.0
Brazil	90.4	86.0	84.0	86.0	104.3	98.4	108.3	87.6	88.6	95.0
Canada	56.1	55.4	41.1	60.3	48.0	49.9	41.2	33.0	37.2	38.0
France	44.5	36.1	32.9	31.2	28.5	21.3	19.1	15.7	14.8	14.0
India	42.3	41.6	37.6	45.0	40.0	40.5	40.3	38.2	40.4	42.0
Liberia	18.5	17.9	18.5	20.0e	17.1	19.4	17.9	14.7	14.9	15.0
South Africa, Republic of	NA	NA	NA	31.1	25.9	27.9	24.2	16.3	24.1	23.0
Sweden	30.0	25.0	21.1	26.2	26.8	22.9	15.9	13.0	17.8	23.0
United States	80.0	55.8	81.5	85.7	69.6	73.2	35.4	37.6	51.3	48.0
Venezuela	17.9	14.2	13.4	16.0	15.8	15.3	11.5	9.6	12.5	14.0
Others	92.3	96.9	93.0	93.9e	73.3	71.4	67.1	57.2	59.0	57.0
Total MEC's	563.8	523.5	505.0	583.0	543.3	524.8	467.3	395.7	449.2	459.0
CPEC's:										
China[e]	64.0	64.0	69.0	73.8	73.8	69.0	68.9	70.0	74.0	75.0
U.S.S.R.	235.2	233.9	237.0	238.2	241.1	238.2	240.1	241.1	243.1	242.0
Others	18.0	22.6	22.6	22.9e	15.4	15.3	14.3	22.8	23.1	23.0
Total CPEC's	317.2	320.5	328.6	334.9	330.3	322.5	323.3	333.9	340.2	340.0
Total world	881.0	844.0	833.6	917.9	873.6	847.3	790.6	729.6	789.4	799.0

[e] Estimated. NA Not available.

The world iron ore industry has been plagued with a number of major problems since 1974. A combination of formerly high energy costs, declining demand, increased competition, and overcapacity have been the root causes of the current dilemma within the industry. The immediate outlook continues to portray an excess of capacity compared with the demand for iron ore. Table 2 illustrates the utilization of the marketable iron ore production capacities of the 10 largest MEC iron ore producers during 1982.

Improvement in the quality of iron ore entering the international trade is likely to continue. This trend, however, is expected to diminish as technical and cost factors eventually will limit the degree to which the iron content of ore can be improved.

Investment cost projections on individual projects have been severely impacted by inflation. Cost escalations of 50 to 100 pct within a period of 18 to 24 months have been experienced. Since it takes several years to plan, construct, and bring a new iron ore project on line, the impact inflation could have on the final cost of a project is enormous. The expense of complying with environmental regulations, particularly in the developed areas like North America, has also had a costly effect on the iron ore industry. Even in developing countries, environmental considerations are beginning to impact iron ore operations. Labor costs have also played a role in the worldwide economics of the iron ore industry, particularly in the United States, Europe, Republic of South Africa, Canada, and Australia.

Also, overcapacity within the steel industry due to lower demand in the United States and the European Economic Community (EEC) has forced closure of some blast furnaces and steel mills. The major factors affecting the low U.S. utilization have been the heavy penetration of foreign steel into U.S. markets, a lower usage of steel by the depressed automobile and construction industries, and the increasing use of scrap in electric arc furnaces.

To further compound the problem of excess plant capacity, the developing countries, which furnish nearly half of the total world supply of iron ore to the developed countries, are now developing ambitious steel industries of their own. The rapid growth of crude steel production in these countries is in sharp contrast to the stagnation of production in the developed nations. Production of steel in developing countries more than doubled from 31 Mmt in 1972 to 65 Mmt in 1981. During the same period, production in the developed countries decreased by nearly 3 pct, from 403 to 392 Mmt. The share of Western World crude steel production from the developing nations in the 10 yr prior to 1981 rose from 8 pct to 17 pct. The significance of the developing countries' contribution to overall steel production in the Western nations will affect the demand and consumption of iron ore in other Western nations.

Table 2.—Utilization of mine capacity in the 10 largest MEC iron ore producing nations, 1982

Country	Capacity, MMlt	Utilization, pct
Australia	124.3	69.5
Brazil	119.2	90.9
Canada	62.3	66.1
France	27.5	69.5
India	58.1	69.4
Liberia	21.4	83.6
South Africa, Republic of	34.8	69.5
Sweden	28.8	55.2
United States	93.2	38.0
Venezuela	23.5	48.9
Total or wtd av	593.1	67.5

Source: American Iron Ore Association.

Several factors have profoundly influenced steel production in the industrial nations. Foremost were the rapid development of continuous casting techniques, which increase the yield of finished steel, and the increasing number of electric arc furnaces that produce steel mainly from scrap rather than from ore. In addition, there were important changes in the type of steel being consumed and technological improvements in steel utilization. This resulted in the reduction of steel consumption in building and civil construction and vehicular manufacturing industries.

The smelting of iron ore into pig iron in blast furnaces is the most common ironmaking method. The reduction of iron ore into sponge iron or direct reduced iron (DRI) only amounts to 1 to 2 pct of world output.

The direct reduction (DR) process normally uses relatively pure lump ores or high-grade pellets. Even though the number of DR plants is increasing, the impact of this process on the world iron ore market is not yet significant except for some domestic markets in Venezuela, Mexico, and Indonesia. In the future, however, DR's market importance will be somewhat greater as additional plants are built. While most current DR plants are in developing countries where there is an abundance of inexpensive natural gas, there have been closures of some DR plants in developed countries due to high fuel costs.

Another commodity that influences the demand for iron ore in the steel industry is the availability of ferrous scrap. Ferrous (iron and steel) scrap is used as the major metallic charge to U.S. electric steelmaking furnaces (electric arc furnaces or EAF) and averages about 27 pct of the metal charge to basic oxygen furnace (BOF) steelmaking furnaces. One long ton of ferrous scrap, based on iron content, is equivalent to about 1.6 lt of iron ore. With the electric arc furnace requiring virtually no pig iron, the amount of pig iron and therefore iron ore required to produce the same amount of steel has decreased. Since 1970, the scrap industry has risen from 15 pct to 27 pct of the total steel industry and is estimated to represent more than 32 pct by the end of the 1980's. In addition, when scrap prices are low, a reduction in the demand for iron ore generally occurs.

The improved yield of rolled steel per ton of raw steel through the increased application of the continuous casting process has been another technical improvement that has reduced the demand for iron ore. In 1984, the U.S. steel industry processed 40 pct of its molten steel in continuous casting, compared with 72 pct in Japan, 88 pct in Italy, and 32, 48, and 51 pct in France, the Federal Republic of Germany, and the United Kingdom, respectively. Within the past 10 to 12 yr the U.S. steel industry's total energy consumption has been reduced by 50 pct and its energy efficiency has improved by 25 pct, according to the American Iron and Steel Institute. This improvement is attributed to energy savings in continuous casting by bypassing a number of energy-intensive operations including gas-fired soaking pits. The yield of salable products from molten steel is also increased, resulting in less energy consumed in resmelting and reprocessing internally generated scrap. Along with the greater use of agglomerates, which has enhanced blast furnace efficiency, the ratio of total iron ore consumption to pig iron production was reduced from 1.83 in 1960 to 1.76 in 1980 as a result of improvements in ore grade and ore processing efficiencies.

The probable demand for iron in ore in the United States is expected to reach 55 MMst in 1990, assuming an average growth rate of 3 pct/yr from 1983 through 1990. Concurrently the rest of the world demand for iron in ore is expected to be 520 MMst in 1990, an average annual growth rate of 3.1 pct (*2*).

The crude steelmaking capacity in the developing countries could increase to 110 Mmt by 1987-88 from a level of 33 Mmt in 1973-74, according to an October 1982 estimate by the International Iron and Steel Institute (*3*). Conversely, there will be a decrease in crude steelmaking capacity in the industrialized countries, with the possible exception of Japan. The North American steel industry, and particularly that of the United States, will be forced to make major improvements in order to compete with the cheaper steelmaking capability of the developing nations.

ECONOMIC IMPACT OF GOVERNMENT-CONTROLLED OPERATIONS

In many of the iron ore producing countries, Governments control much of the iron ore production through full or partial ownership of the mines. Brazil, Chile, France, India, Liberia, Mauritania, Mexico, Norway, Peru, Republic of South Africa, Sierra Leone, Sweden, and Venezuela are some of these countries. Theoretically, Government participation ensures that the benefits derived from capitalizing on a country's resources are received by that country. Consequently, this control can create distortions in the traditional market economics of iron ore production for both domestic and export markets.

Iron ore is a major source of foreign exchange for some developing countries. The foreign exchange is needed to pay for imported goods and to further develop the countries' economics. In the quest for more foreign exchange, developing countries tend to increase their level of exports of iron ore to obtain more revenues. As the demand for ore declines, this increase in production adds to the already existing problems of oversupply and depressed prices for iron ore. Consequently, Government owned or controlled mining operations in less developed countries may maintain production levels in order to obtain foreign exchange earnings, which may result in large losses in terms of U.S. dollars. The effect, though, continues to weaken the market for their own product.

Another economic effect of Government ownership or control is that iron ore companies that are not operating profitably are still able to stay in business through Government support. The Swedish iron ore mines have been in serious financial trouble for a number of years and are being supported by the Government. Sydvaranger, a Norwegian iron ore mine, has been receiving grants from the Government for many years. In France, most iron ore mines are assisted by the Government, partly to ensure a supply of ore for its domestic steel industry but especially to maintain employment. The Peruvian Government provided export tax relief on sales by granting an exemption on the 17.5-pct export tax in late 1980, which enabled the Marcona property to show an artificial profit for that year. In all of these cases, there are reasons other than profit considerations for keeping the mines open.

INTERNATIONAL TRADE

The percentage of world iron ore that is traded internationally rose from about 30 pct in 1961 to about 42 pct in 1980 and remained about the same in 1983 and 1984. The total international trade volume reached a high of about 373 MMlt in 1979 (*4*).

In 1985, six nations accounted for more than 80 pct of iron ore exports. Similarly, three consumers—Japan, the EEC countries, and the United States as a distant third—import over 80 pct of the iron ore traded on the international market. Figure 1 shows the major exporting and importing countries of iron ore in the international market; figure 2 shows the world trade pattern for the early 1980's.

Import penetration of foreign iron ore into the United States is mainly limited to the U.S. Atlantic and gulf coasts and the Great Lakes. Factors that limit import penetration are port depth and size of locks into the lakes, causing only smaller ships to transport ore, thus creating higher shipping costs. The Japanese steel industry relies on imported ore because Japan has virtually no iron ore resources. The European steel industry (excluding Scandinavia), however, was originally established to use local ores. Due to the marginal quality of the ores, which grade mostly between 25 and 35 pct Fe, and the associated increased costs for pig iron production, the EEC countries now import about 80 pct of their required iron ore. Imports of iron ore vary from one country to another. France only imports about 50 pct of its requirements, with the rest of its needs met by domestic production, but the Federal Republic of Germany, the Netherlands, and Italy each import over 90 pct of their iron ore.

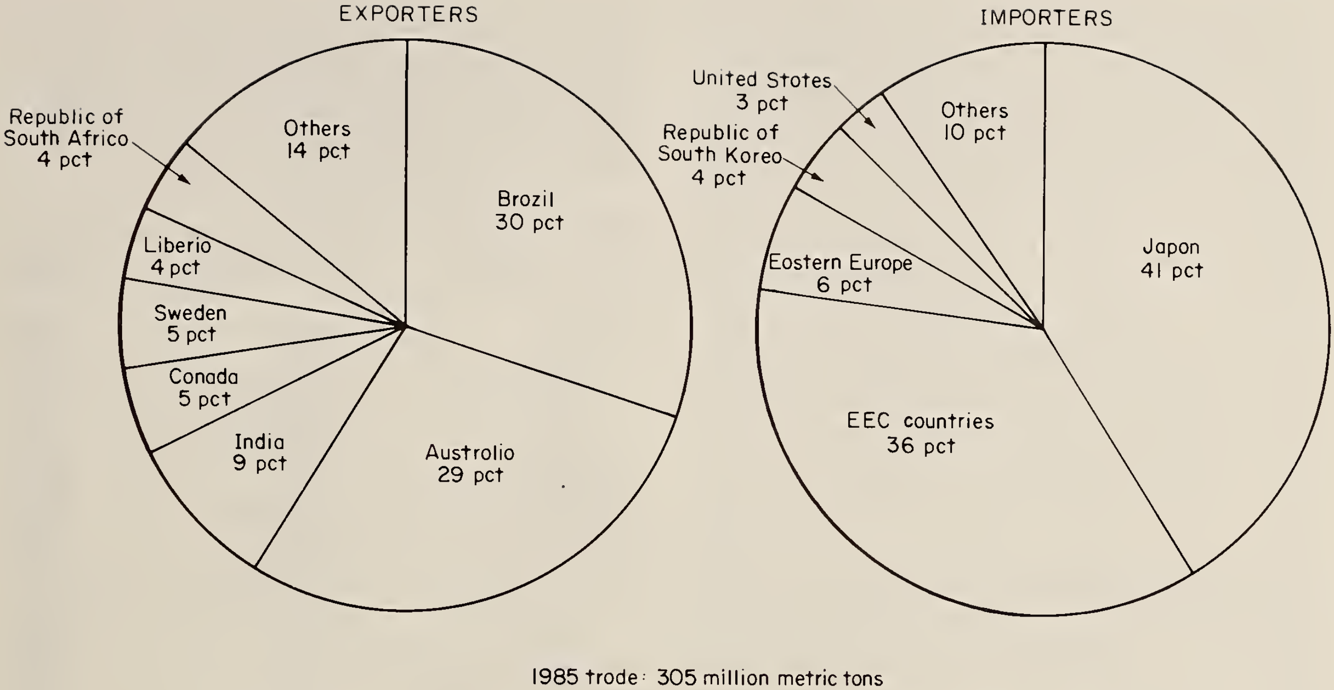

Figure 1.—Major exporters and importers of iron ore in the international market in 1985.

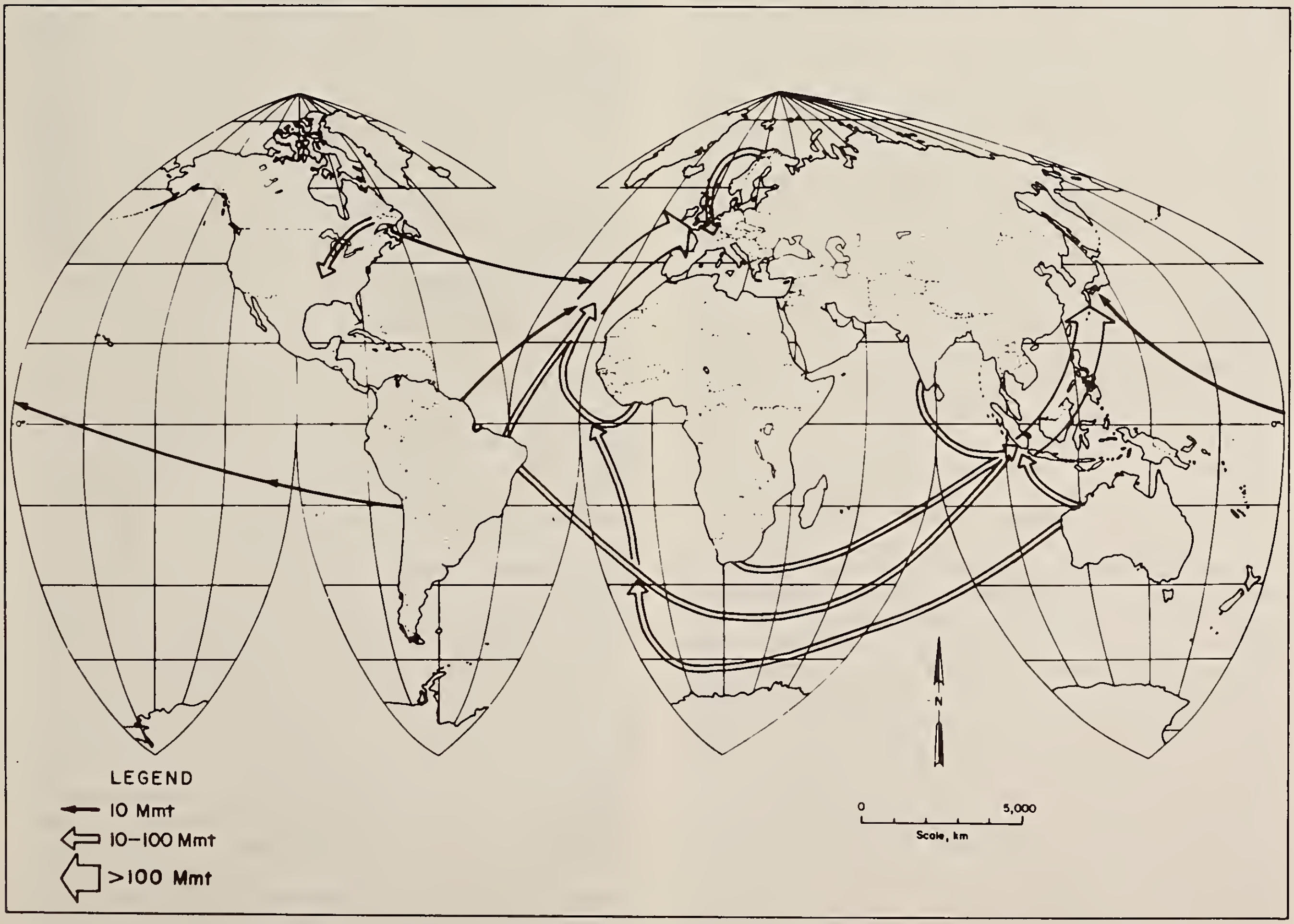

Figure 2.—World iron trade pattern, early 1980's.

Taken as a group, the developing countries constitute only 9 pct of the world raw steel capacity yet make up 40 pct of the total global iron ore production capacity (*5*). One of the policy aims for a number of developing countries is to try to establish or expand their steel industries. This is based on the premise that the development of a steelmaking industry will have a profound impact on the entire industrial and social development of the country. This trend is reflected in the rapid increase in iron ore consumption in the developing countries, which averaged 5.7 pct/yr in the 1970's. In contrast, the consumption of iron ore in the developed countries decreased at a rate of 0.7 pct/yr (*6*).

Contracts covering a relatively long period of time constitute the major share of all iron ore transactions between the steel mills and their supplying mines. The Japanese and European (EEC and Eastern European countries) steel industries meet about 90 pct of their import requirements under this type of arrangement. The balance represents sales on the spot market or under relatively short term contracts.

The steel producers have established very close relationships with most iron ore mines that assure the steel producers of a stable source for their ore. In the past, large consumers have reduced their supply risk through direct investment in additional mines and/or long-term contracts with other mines, resulting in a diversification of sources for iron ore. In addition, buyers have assured themselves of a more than adequate supply of iron ore by offering long-term contracts or establishing partial ownership with the mines. Such guaranteed markets have been necessary for the mine owners and their financial backers to justify the large investments needed to develop the mines.

In the past, under the long-term supply contracts, the iron ore industry was able to achieve and develop a healthy growth based upon anticipated demand. However, in recent years, a gradual reduction of the stability provided by these long-term arrangements has been witnessed. In many cases the steel mills accept only 60 to 70 pct of basic contractual tonnages, making the usual 10-pct quantity variation clauses appear meaningless. This has increased the tendency to achieve wider quantity margins and shorter contract durations. The persistence of this trend, coupled with the apparent latitude in approach to the quantity margins, can result in the diminishing value of these contracts with adverse effects on the mining operations and the shipping industry.

INTERNATIONAL TRANSPORTATION

The iron ore mines in many countries export much, if not all, of their product, and most of this is traded via ocean routes. In the world seaborne trade, iron ore is one of the most important dry cargo commodities and has grown rapidly since the mid-1960's. Shipments rose from 152 Mmt in 1965 to 330 Mmt in 1974—equivalent to an average growth of about 9 pct/yr (*7*). During those years many mines were developed with the export market in mind, and the resulting world iron ore trade patterns changed considerably. Accompanying this change in trade patterns was an increase in the size of ships used to haul iron ore, the necessity to develop port facilities that would accommodate the large ships, and an increase in the average length of ocean shipping distances.

Most of the iron ore mines that export ore are located in different continents than the steel mills to which they sell their ore. Many of the mines that sell in the export market produce very large quantities of iron ore products that have a relatively low unit value. Hence, it is necessary to have a transportation system capable of handling the large tonnages and vast distances in a very inexpensive manner. Table 3 shows locations and capacities of iron ore exporting ports that were used in this study.

Table 3.—Location and capacities of iron ore exporting ports

Continent and country	Port name	Capacity, DWT
Africa:		
Algeria	Annaba	[e]100,000
	Tarfoya	[e]90,000
Cameroon	Kribi	[e]100,000
Gabon	Santa Clara	[e]150,000
Ivory Coast	San Pedro	[e]200,000
Liberia	Buchanan	85,000
	Monrovia	85,000
Mauritania	Nouadhibou	110,000
Senegal	Sedar	[e]200,000
Sierra Leone	Pepel	100,000
South Africa	Saldanha Bay	300,000
Asia: India	Mangalore	60,000
	Mormugao	[1]50,000
	Vishakhapatnam	[1]50,000
Europe:		
Norway	Narvik	350,000
	Kirkenes	125,000
Portugal	Seixal	[e]100,000
Spain	Almeria	90,000
Sweden	Lulea	60,000
North America: Canada	Port Cartier	125,000
	Pointe Noire	75,000
	Sept-Iles	230,000
Oceania: Australia	Dampier	200,000
	Port Latta	95,000
	Port Hedland	225,000
	Port Walcott	265,000
	Whyalla	70,000
South America:		
Brazil	Ponta do Ubu	200,000
	Rio de Janeiro	40,000
	Sepetiba	250,000
	Tubarao	300,000
Chile	Guacolda	160,000
	Guayacan	170,000
	Huasco	160,000
Peru	San Nicolas	170,000
Venezuela	Palua	70,000
	Puerto Ordaz	100,000

[e] Estimate for proposed port.
[1] Up to 150,000 DWT can be loaded in deeper water.

Source: Cargo Systems Research, Ports of the World.

Transportation, as an element of ore price, constitutes a large part of the cost of iron ore. Rates for ocean shipments of iron ore are dependent upon a number of variables. Among these variables are the size of the vessel, the design of the vessel to handle joint cargos with the ore or to backhaul or crosshaul some other cargo (such as oil or grain) during some segment of its journey, the nature and capacity of loading and unloading facilities at different ports, the ownership of the vessel, competition for cargo space at any given time, and terms of the contract. In general, a "spot" shipment (short-term contract) in a fairly small vessel can cost several times more on a per-ton basis than shipment in a large vessel under a spot or long-term contract. Around 90 pct of international iron ore trade is under long-term contracts. Figure 3 shows the wide range and variability of ocean freight rates for various routes in the early 1980's.

The use of larger vessels has become more and more common in the international shipment of iron ore because of large volumes of ore and the need to reduce unit cost. Routine loading of vessels in the 100,000- to 200,000-DWT classes is common in Brazil and Australia, with some cargos even larger. Deadweight tonnage (DWT) is the carrying capacity of a vessel in long tons and is measured as the difference between the ship's weight and its displacement

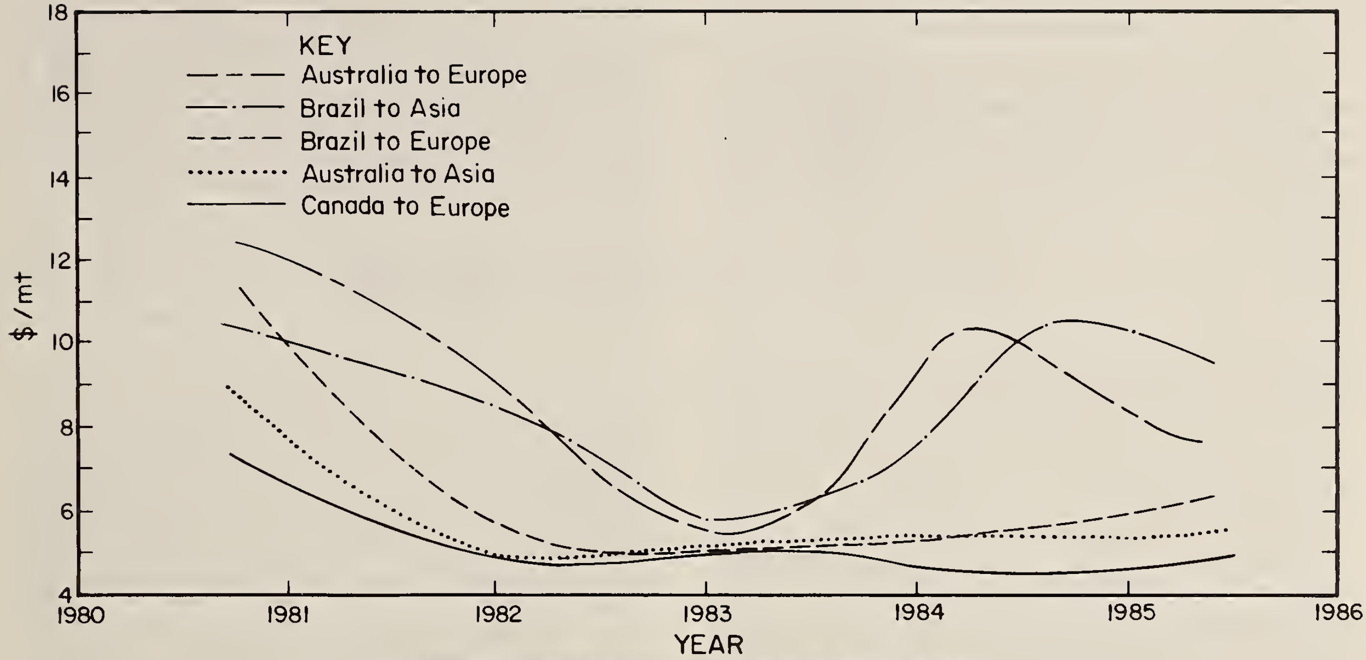

Figure 3.—Ocean freight rate fluctuations, early 1980's.

when loaded. The development and use of large ships has enabled iron ore to be transported at very low costs. It is not unusual for large users and large shippers of iron ore to both own and operate their own vessels. For larger vessels the cost per ton of iron ore transported will decrease because the added expenses due to size are small relative to the extra capacity. The cost decreases are due to lower capital costs, per ton of capacity, less required horsepower per DWT, and fewer required crew members per DWT.

Many ships are of the combined carrier configuration, and about 60 pct of them are at least 100,000 DWT. In fact, most major volume long-haul trade routes are open to the 150,000- to 200,000-DWT size ships. These ships are either oil-bulk-oil (OBO) or ore-oil (O/O) carriers. This facilitates backhauling of cargos more effectively, resulting in higher use rates and more competitive pricing structures. More shipments of bulk cargos, such as oil, ore, coal, and grain, are moved from the Atlantic Basin to the Pacific Basin than the reverse. As a result, there is a tremendous competitive pressure on many dry bulk carriers to secure backhaul cargos from Austrialia and the Far East. Thus, it is possible for countries like Australia to ship iron ore and bauxite to Europe at much cheaper rates than generally accepted for the distance involved.

Ocean transport costs for iron ore are a function not only of the size and type of vessels used but also of the time taken to load and discharge, as well as of the distance over which the product is transported. The type and efficiency of the port facilities available at either end of an ocean transport leg affect all other factors except the shipping distance. Generally, it is not feasible to develop large iron ore loading facilities at existing ports because of such factors as mine location, limited available water depth, unsuitable or inadequate infrastructure, and congestion. The construction costs of port facilities are high and include the costs of dredging to obtain and maintain the necessary water depths.

Japan and Western Europe have the great majority of the existing large carrier ports receiving iron ore imports. Since the mid-1960's, many steel mills have been built in locations adjacent to iron ore discharging terminals on the coasts. Most of the large carrier ports are controlled by the steel companies, and incoming raw materials are usually discharged directly to adjacent coastal steelworks. However, in the Federal Republic of Germany, for example, imports are barged up the Rhine River to the steel mills. There are also transshipment terminals (which transfer cargo from large, deep-draft, ocean vessels to rail cars or to smaller, shallower vessels capable of river navigation) for iron ore cargos, the majority of which are located in Western Europe. Facilities of this type are owned either by inland steel manufacturers or by stevedoring companies specializing in iron ore.

The iron ore ocean freight industry is not a fully competitive market. Iron ore is generally transported under unpublished long-term charter arrangements. In addition, major steel companies have ownership or control in many of the companies that ship iron ore, and some quoted freight rates are simply intercompany book entries. Buyers of shipping services, normally the steel producers, can influence freight market developments without resorting to direct investment in shipping. They can promote investments by independent operators or subsidiaries by entering into charter arrangements of sufficient duration to allow capital amortization of the vessels within the contract period. They can also discriminately award contracts with freight rates that are initially favorable to the shipping company even before a ship is constructed. This way they can avoid direct investment and insure an adequate supply of ships and established shipping costs. Because some of the ships are so large and are also specialized, they can be accommodated at comparatively few ports. This severely restricts their ability to be used to carry other cargo when iron ore is not available.

Depressed iron ore market conditions continue to affect the ocean freight industry, especially the large bulk carriers. Due to the present weak demand for iron ore and an oversupply of ships, major changes will have to take place in order to restore the steel or shipping industry market equilibrium. However, some additional large bulk carriers are still being built, making it more difficult to reach satisfactory trading conditions for shipowners.

INLAND SHIPPING

About two-thirds of the iron ore products imported into the United States are from Canadian mines and are received at the Great Lakes ports. The remainder are offloaded at a few ports on the east coast and gulf coast. The major problems with the importation of iron ore into the United States are the berth and channel draft limitations that limit access to lake ports almost exclusively to vessels of 65,000 DWT or less.

An extremely large volume of material is moved over the Great Lakes, including 80 pct of the raw materials needed for steelmaking. The lakes and connecting waterways between the railheads and mills form one of the country's most effective transportation systems. Due to the impact of transportation charges and different markets, iron ore from the Great Lakes area is not cost-competitive with overseas ores unloaded on the gulf coast or the east coast of the United States.

Ships used in the Great Lakes trade (Lakers) are different from those used in ocean trade. They are long and narrow with a comparatively shallow draft, have a maximum size of about 60,000 DWT, and are designed to pass through the locks on the waterways between the lakes. The new iron ore carriers on the Great Lakes are exclusively self-unloading. The ships unload via self-contained conveyor systems and are able to do so quickly, inexpensively, and at offloading points where facilities are minimal. They can also unload directly into waiting rail cars or river vessels, thereby reducing turnaround time and saving on additional handling costs.

PRICE STRUCTURE

Japanese and European steelmakers dominate the market for iron ore, and, to a great extent, control the iron ore prices. Individual steelmakers normally do not negotiate their own contracts; most negotiations are done through industry-oriented buying organizations. Steel mills, however, have their own individual iron ore specifications that govern the negotiations for various ore products.

Iron ore accounts for only 10 to 15 pct of the total cost of steelmaking, and iron ore prices have little correlation with the price of iron and steel and the fluctuations of the iron and steel industry. Because of geographic locations and volume of sales, quality of ore, and type of product, Australia and Brazil are the price leaders for the iron ore exporting countries. Most of the iron ore is bought by multiyear contracts on a tonnage basis, with renegotiation of prices normally done annually.

Iron ore is not a homogenous commodity with respect to chemical composition or physical form. Consequently, pricing methods are complex to reflect these characteristics. An ore with a specific quality (includes grade, deleterious substances, size, etc.) will have a small price range. Prices are established on an iron unit basis. This price is derived through an agreement between the seller and the consumer on a unit price per iron unit basis and is not officially fixed (*8*).

On the international market the price for iron ore is usually a negotiated free on board (f.o.b.) price. However, there are some exceptions to this, such as Venezuelan, Brazilian, and Australian ore being sold cost and freight (c&f). The delivered price, or cost, insurance, and freight (c.i.f.) price, is usually the price from which the f.o.b. price is derived, and is the price with which the steel producers are basically concerned. The prices for c.i.f. and c&f tend to be equal in a given market for similar products (*9*). Iron ore buyers will generally negotiate contract prices for iron ore to be equal to other ores of a similar quality to their consumers. The f.o.b. price is then artificially determined by subtracting the estimated ocean freight cost from the c.i.f. price; it is used as a basis for reimbursement to the producer. Hence, transportation costs are actually borne by the producer. Differences in c.i.f. prices between various iron ores delivered to a particular steel mill are, therefore, due to differences either in quality of type of ore or in the type of contract and date of negotiation, or in shipping cost.

The prices on the international market do not govern the domestic prices for ore that is sold internally. Mexico, Venezuela, and other countries sell iron ore for use internally, especially to Government-owned mills. This is somewhat true for the United States. The domestic ore prices are based on the Great Lakes price schedule as a reference point that governs both merchant and captive transactions. These prices, however, are only for the Lake Superior ores and do not necessarily govern prices of ore produced elsewhere in the United States. The pricing

Table 4.—Domestic iron ore prices
(Per gross ton of 51.50-pct-Fe natural ore, delivered at rail of vessel Lower Lake port)

	December 1977	December 1980	December 1984
Mesabi non-Bessemer	$21.18	$28.50	$30.03-31.58
Coarse	21.98	NA	NA
Fine	20.73	NA	NA
Old Range non-Bessemer	21.43	28.75	NA
Manganiferous	21.43	24.55	32.78
Pellets, per natural long ton iron unit	.555	.805	.66-.869

NA Not available.

Source: Skillings' Mining Review.

Table 5.—International iron ore prices, 1984

Market and supplier	Product	Price, $/Fe unit
European market:[1]		
Australia[2]	Fines	0.33
	Lump	.36
Brazil	Fines	.26
	Pellets	0.34-.36
Canada	Concentrates	.27
South Africa, Republic of	Fines	.21
	Lump	.24
Sweden and Norway	Pellets	.37-.39
	Fines	.27-.29
Venezuela[2]	Fines	.33
West Africa	Fines	.24-.28
Japanese market:[3]		
Australia	Fines	.26
	Lump	.31
Brazil	Fines	.24-.25
	Pellets	.20
	Lump	.24
Canada	Fines	.23
Chile	Fines	.21
	Lump	.23
	Pellets	[4].35
India	Fines	.20-.26
	Lump	.26-.30
Liberia	Fines	.22
New Zealand	Iron sand	[4].19
Peru	Fines	.20
	Pellet-fines	.20
South Africa, Republic of	Fines	.24
	Lump	.27-.28

[1] Price is dollars per lt Fe unit, f.o.b. unless otherwise noted.
[2] c&f.
[3] Price is dollars per mt Fe unit, f.o.b. unless otherwise noted.
[4] 1983 price.

Source: TEX Report, Bulk Shipping Costs and Commodity Markets.

schedule used on the Great Lakes is based on the price of ore delivered at "Lower Lake port," or "Upper Lake port," or "delivered rail of vessel, Lower Lake port." The published prices are set at the given receiving port regardless of the distance between the shipping and receiving port. Even though the Lower Lake pricing system was developed when the United States imported very little iron ore, it has a strong bearing on current prices paid for South American and African ores.

Table 4 gives some domestic prices in 1984 for various iron ore products. International iron ore prices are given in table 5 and are shown for the two major markets of iron ore products, Europe and Japan. Note that some of the prices are based f.o.b., while others are on a c&f basis.

IRON ORE RESOURCES AND PROCESSING

GEOLOGY

The major forms of iron worldwide, as classified by their chemical composition, are hematite, magnetite, goethite or limonite, siderite, and, rarely, pyrite. Hematite, magnetite, and goethite, all iron oxides, are the three most common iron ore minerals. Some deposits of siderite (iron carbonate), pyrite and pyrrhotite (iron sufides), and chamosite (an iron silicate) are mined but are of minor economic importance at the present time. Mineral impurities exist in any iron ore and are relevant to the discussion of the nature of iron ore. Typical gangue minerals are quartz, iron silicates, calcium-magnesium iron carbonates, clay minerals, apatite, and manganese oxides.

There are many different types of iron ore deposits, but the vast majority of them can be classified as either bedded sedimentary deposits or massive deposits. Bedded deposits in Precambrian rocks, called banded iron formations (BIF's), are by far the most important sources of iron ore. Occurrences of these deposits are predominantly in the Precambrian Shield areas of the world. BIF's are thinly bedded chemical sediments containing at least 15 pct Fe and normally containing chert layers. The BIF's are usually folded and have low to steep dips. Thicknesses normally average a few hundred feet but may range from less than 25 ft to more than 2,000 ft. The beds are exposed in belts ranging from a few miles to several hundred miles in length, although distances of a few tens of miles are more common.

The term "taconite" is a local term used in the iron-bearing district of the Mesabi range in the Lake Superior Region of the United States. Generally, taconites are bedded ferruginous charts of extremely hard ore in which the iron is in either banded or well-disseminated form containing hematite, magnetite, carbonate, or silicates, or a combination of these. Since World War II it has been considered a low-grade iron formation suitable for concentration of magnetite and hematite, from which pellets containing 62 to 65 pct Fe can be made. Deposits in BIF's with iron contents about 25 pct that are amenable to beneficiation are considred taconite-type deposits. The taconite ores are low-grade deposits containing 15 to 35 pct Fe and 40 to 55 pct SiO_2.

Most North American iron formations contain 30 pct or more total iron, 60 to 80 pct of which is economically recoverable. South American itabirites are usually richer in iron content than those in North America, grading about 40 pct Fe. Itabirite is a laminated, metamorphosed iron formation in which the iron is present as thin layers of hematite, magnetite, or martite. The term was originally applied in Itabira, Brazil, to a high-grade massive specular-hematite ore (66 pct Fe). Metamorphism has sometimes caused a coarsening of the grain size, which has improved the beneficiation qualities of the deposits. Billions of tons of ore containing more than 64 pct Fe are in the Brazilian itabirite formations, with some deposits containing almost pure hematite.

Oolitic ironstones of Paleozoic to Cretaceous age comprise another class of bedded iron deposits of regional importance in the Southeastern United States, Western Europe, and North Africa. They differ from the BIF's in that, although they are laterally extensive, they are usually less than 50 ft thick and usually average only 25 to 35 pct Fe. The ore consists of very fine grained hematite, quartz, chamosite, and siderite in varying proportions and is usually high in phosphorus. On a global basis, the relative significance of these ores is small.

Iron occurs in several types of massive deposits found mainly in tectonically deformed belts of the earth and associated with igneous intrusions. The most important types appear to be magmatic segregations, and injection, sedimentary, and extrusive deposits. Grades of iron ore range from about 30 pct to 65 pct Fe. Some of these deposits contain minerals of copper, titanium, phosphorus, vanadium, or other metals that may be produced as byproducts. Most of the apatite presently produced in Sweden is recovered from iron ore tailings. In the past, gold has been produced from iron ore operations in Minas Gerais in Brazil. Copper, cobalt, minor amounts of nickel, and unspecified amounts of gold and silver occur in the ore at Hierro, Peru. Manganese, cobalt, phosphate, copper, gold, and silver have all been recovered from domestic iron ore operations.

Clastic accumulations of magnetite in beach sands are a minor source of ore and usually contain titanium. Another minor source of ore is river bed deposits containing titanium. Another minor source of ore is river bed deposits containing goethite, such as the Robe River deposit in Australia. Iron ore also occurs as laterites formed in tropical areas. The use of laterites as a iron ore is limited because of major impurities such as clay, chromium, cobalt, and nickel. In addition to laterites, other residual deposits are also formed by weathering of iron-rich rocks that formed the Mesabi range direct shipping ores and the ore at Schefferville in Canada.

Manganese and titanium occur along with iron in deposits in many countries around the world. The pellets at Wabush in Canada are produced from an ore that has a high manganese content. Concentrates from titanomagnetite beach sands are produced to provide the basis for the iron and steel industry in New Zealand. India produces a substantial amount of manganiferous iron ore used for blast furnaces. These types of deposits were included in the study if the iron ore was of sufficient quality and the magnetite or titanium was of a relatively low grade. Manganiferous and titaniferous iron ores are more important to the manganese or titanium industries and therefore were not evaluated in this study.

IRON ORE MINING

Iron ore mining systems for mines evaluated in this study are generally all open pit; the most notable exceptions are the underground mines of northern and central Sweden. Mining methods are essentially the same for foreign and domestic iron ore. Computer technology has been incorporated into many of the mining and beneficiation processes to increase efficiency and reduce personnel requirements.

While conventional ore breakage, employing drilling and blasting variations, is most universally used, several other unique systems are being utilized in some of the mines. In New Zealand, water-jet drilling is used to loosen the iron sands of the Waipipi deposit. After the 130-ft-thick deposit is loosened by the high-pressure water jets, the actual mining is then carried out by dredging or scraping along an 800-ft face.

Marampa in Sierra Leone (west Africa) is yet another mine using unique systems of ore recovery. The mine has been brought on line again after a 7-yr closure. Conventional bench mining is practiced, while the "tailings pond ore" is mined with a dredge. The dredge digs to a depth of 33 ft with a 14-in-diam suction head. This secondary ore, produced at a rate of 1.35 Mmt/yr, is then pumped to the concentrator. The "tailings pond ore" contains 40 Mmt of 28.6 pct Fe.

The Savage River Mine in Tasmania employs mining practices, some of which are normally confined to underground operations. Due to the complex geology of the ore body, very stringent pit control is required, including rockbolting, special terminal blast conditions, and pit dewatering. Heavy rainfall in the area of 2,000 mm (79 in) annually requires that the pit be designed with a 2-pct grade to assure proper drainage into the Savage River. Pumping of the pit will be required for the final four benches as the pit will be below the level of the river.

The Sishen Mine in the Republic of South Africa is one of the largest open pit mines in the world, with a future potential of expanding into underground production as well. Due to rising fuel costs, a trolley-assisted truck operation was tested and installed for full operation in 1984. A 20-pct decrease in diesel fuel consumption has occurred with this computer-controlled trolley system.

The Swedish mining industry has been long recognized as a leader in new methods, new equipment, and innovative mining practices throughout the world. The underground rail haulage system at the Kiruna Mine is operated from one central underground control room. The operator has complete control over all the ore chutes, loading points, and unloading of a completely automated rail system. Monitoring of the system is done by strategically placed television cameras with the television screens located in the control room. Kiruna employs a sublevel caving method, as does the Malmberget Mine, which is one of the largest underground mines in the world, and the second largest mine in Sweden. Prior to converting to sublevel caving, the mine also employed room-and-pillar and shrinkage stoping mining systems. A major problem associated with the sublevel caving mining method is the resultant subsidence effects on the surface environment. In the case of the Malmberget operation, the town of Malmberget had to be relocated to insure safety. The Malmberget Mine employs truck haulage rather than rail, and transports the ore in 45-st trucks to the primary crusher underground. Trackless haulage was selected mainly because it offers more flexibility than rail.

The Kudremukh Iron Ore Company Limited, a Government-owned enterprise of India, has constructed the largest new iron ore project in the world at Kudremukh in southern India. The mine is scheduled to produce an average of 90,700 mt/d at full capacity. The mining methods to be employed are similar to those at large opencast mines elsewhere in the world. The mine will employ the largest mining equipment in India, utilizing 120- to 150-mt-ore haulage trucks. Haulage roads have been specially constructed to provide protection against the ravages of the monsoon season. A unique aspect of this project is that manual labor had not yet been replaced by machines during its construction phase. At the project's peak about 20,000 people were employed by the contractors. The operation will employ about 3,100 people at full production capacity. The entire operation, including crushing, beneficiation, slurry transport of ore concentrate, filtration for production of concentrate cake, and port facilities, will be computerized.

Common haulage methods used to transport ore to a beneficiation plant include rail, trucks, and conveyors. Rail and conveyors are most often the least expensive haulage method; however, the geometry of the ore body, depth of the pit, and other factors dictate the methods used at any particular site. Combination haulage methods, utilizing conveyors, rail, and trucks, are common in many surface operations.

Different systems of ore haulage, while not unique, are employed at various operations. The El Encino Mine in Mexico employs an aerial tramway to transport crushed ore 22 km to the concentrator and pellet plant. The La Perla Mine and the Las Hercules Mine in Mexico are connected by a 379-km slurry pipeline to carry ore to a new pellet plant at Monclova, Coahuila. The pipeline has a capacity of 4.5 Mmt/yr. The Kudremukh Mine in India operates a slurry pipeline with a capacity of 7.5 Mmt/yr. Another system of ore transportation is employed at the Cerro Bolivar and Altamira Mines in Venezuela, which is similar to haulage at the Reserve Mining Co. deposit in Minnesota. At these mines trucks haul the ore where it is dumped directly into railroad cars. The unit trains then travel 145 km to Puerto Ordaz where they pass through a single rotary dumper to unload the ore.

BENEFICIATION METHODS

Iron ore is categorized as to its size and type of processing. It can be classified as crude ore, which is an unconcentrated ore as it leaves the mine. If this ore can be used with minimal crushing and screening, it is considered direct-shipping ore. However, almost all iron ore mined is beneficiated in order to obtain uniformly sized products, improve the iron content, and eliminate impurities. The products (either coarse or fine) of beneficiation plants are called concentrates. Agglomeration of fine concentrates and some natural ores is done to facilitate transportation and smelting. The agglomerates are called pellets, sinter, briquets, or nodules, depending upon the nature of the agglomeration process.

Physical properties of iron ore are important in beneficiation and affect milling costs. Magnetism is important, for the concentration of both magnetite and hematite (hence the use of high-intensity magnetic separators). Specific gravity differences permit concentration of ores by washing, heavy-medium separation, and the use of Humphreys spirals, Reichert cones, cyclones, etc. Some ore can

be concentrated merely by screening. Physical-chemical differences permit concentration by flotation. Chemically combined water in hydrous minerals such as goethite (limonite) is hard to drive off; hence, such ore contains less iron and results in a lower price.

Crude ore may be of direct shipping quality, which only requires a crushing and screening process followed by direct shipment to the blast furnace. The concentration methods that may be utilized include crushing, screening, heavy-media separation, jigging, and dewatering. Fines are further processed by sintering to produce an acceptable product.

Primary crushing is carried out in jaw crushers, gyratory crushers, or rolls. Secondary crushing is normally accomplished in a cone crusher, by rolls, or in a hammer mill. Grinding is mainly carried out in ball mills or rod mills.

Commonly used methods for iron ore concentration include heavy-media separation, flotation, Humphreys spiral, and magnetic separation. The method used for iron ore concentration depends on several factors: magnetic, mineralogical, and physical characteristics of ore and gangue as well as availability and cost of power, water, and reagents. The method or combination of methods eventually utilized will entail extensive research and pilot plant testing to develop the optimum cost-effective process.

Dewatering, or solid-liquid separation, produces a relatively dry concentrate for shipment. Partial dewatering is also performed at various stages in the treatment, so as to prepare the feed for subsequent processes. The drying of concentrates prior to shipping is the last operation that may be performed in the mineral-processing plant for nonagglomerated products. It reduces the cost of transport and is usually aimed at reducing the moisture content to about 5 wt pct.

AGGLOMERATION METHODS

One of the most important physical characteristics of iron ore is the size of the particles. Iron ore feed that contains fine particles causes operational problems in the blast furnace. Hence, most iron ore, of less than 1/4-in-diam size, must be agglomerated before it can be used in the blast furnace. Agglomeration is a process in which small particles are combined to produce larger, permanent masses. The two principal methods of agglomeration used for iron ore are sintering and pelletizing.

Sinter is made by igniting a mixture of fine ore (1/4 in to 100 mesh), lime or limestone, and coke on a moving horizontal grate. Sinter plants are almost all located adjacent to steel mills because sinter is brittle and deteriorates easily when handled. Another benefit of locating sinter plants near steel mills is that it enables the recovery and the use of steel plant dust and coke breeze, both generated during steelmaking.

Pellets, on the other hand, have excellent handling characteristics and are easily transported. Hence, most pellet plants are located near mines because the fines that comprise pellets are difficult to transport. Pellets are made by combining ore particles less than 100 mesh with a binder, usually bentonite, and then hardening them in furnaces. The pellets produced generally have a very high iron content, rarely less than 60 pct and usually 65 pct or more. Pellets are made by rolling ore with controlled moisture content around in a drum or on a rotating inclined disc. Some small pressure is necessary to consolidate the pellets as they form, but this comes mainly from their own weight applied to each small particle as it is picked up. They are hardened or "indurated" by firing at such a temperature that a good bond is produced either by recrystallization of the minerals present or by the formation of glasses.

Initially, magnetite concentrates were pelletized because the heat of reaction constituted a large portion of the necessary process fuel. Now, however, hematite, mixtures of hematite and magnetite, and mixtures of hematite and limonite can also be pelletized. The exothermic reaction from pelletizing magnetite ore reduces the amount of fuel required and can have a very favorable effect on the economics of an operation. Pellets made from hematite and hematite-limonite ores may require as much as 30 L fuel per long ton of ore, while fuel requirements for magnetite ores are considerably lower. Plants run by LKAB in Sweden use as little as 8 L/lt fuel. Fuels normally used to fire pellet plants are natural gas and/or No. 6 fuel oil.

In recent years, pelletizing has been increasingly adopted by some developing countries. The reasons for this are (1) a desire for increased foreign exchange earnings, (2) a need to utilize a higher proportion of fines, and (3) the production of feed for growing domestic steel industries.

Until the mid-1970's, pellets were a competitive substitute for sinter as a blast furnace feed, but in some cases rapidly rising oil prices caused pellet production costs to rise to levels that eroded any competitive advantage that pellets had over sinter. While overall pellet production has stagnated since 1974, capacity outside North America and the U.S.S.R. continued to increase from about 63 MMlt to over 115 MMlt. Much of this capacity was added in Latin America, particularly Brazil, in an attempt to utilize and add value to iron ore production.

North American capacity utilization of pellet plants has fallen from the levels achieved early in the 1970's. However, owing to the lack of competitive substitutes for pellets in North America, the fall was not as pronounced as expected, at least through 1981.

A main reason for the declining trend is related to fuel price. In 1976-81, OPEC oil prices increased approximately 300 pct. In countries that produce some of their own oil, the fuel price increases were not as extreme; e.g., Canadian fuel price increases were around 200 pct. But in either case, plants were closed either because of high fuel costs or because prices that producers needed to receive for pellets became so high that there was no market for them. Hamersley Iron and Robe River (Australia), the Iron Ore Company of Canada (Spet-Iles, Canada), and LAMCO (Liberia) all closed their pelletizing plants owing to excessive oil prices, for example. Hierro Peru (Peru) closed its oldest pelletizing circuit owing to high fuel costs and low pellet prices. In 1981, the two export-oriented pellet plants in the Goa region of India were closed owing to high fuel oil costs and the inability to pass those costs on to their Japanese customers. Both plants are likely to undergo major modifications to attempt to reduce operating costs.

With respect to the world market, however, the reduction in the production of pellets has not led to a corresponding fall in ore supplies, since the reduced volume of pellets has partly been compensated for by increased quantities of concentrate and fine ore. While some pellet projects have come on line, others have been tabled because of high fuel prices. It is not known at this time if and when their future development will be reconsidered even though fuel prices have fallen.

METHODOLOGY

The Bureau of Mines is developing a continuously evolving methodology for the analysis of long-run mineral resource availability. The flow of the Bureau's Minerals Availability program (MAP) evaluation process from deposit evaluation to analysis of availability information is illustrated in figure 4. In order to determine potential availability of iron ore, the Bureau selected 129 deposits located in 25 MEC's for evaluation, of which 43 are domestic mines or deposits. For each deposit, geologic, mining, and beneficiation data were collected. Data included resource estimates, actual and estimated mine and mill operating capacities, estimated life, and capital and operating costs.

Costs used in this study were actual where available or were estimated by various costing techniques. In addition, data were also collected from other sources such as professional journals, industry publications, and individual companies. Costs for U.S. deposits were developed by the Bureau's Field Operations Centers. The Bureau's cost estimating system (CES) (*10*) was utilized in generating costs for domestic properties. Data for properties in MEC's were collected or developed under contract.

For each iron ore operation included in this study, capital expenditures were calculated for exploration, acquisition, and development; for mine and plant equipment; and for constructing and equipping the mill. The capital expenditures for the different mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, infrastructure, and working capital. Infrastructure is a broad category that includes costs for access and haulage facilities, ports, water facilities, power supply, and personnel accommodations. Working capital is a revolving cash fund required for operating expenses such as labor, supplies, insurance, and taxes.

The total operating cost of a mining project is a combination of direct and indirect costs. Direct operating costs include operating and maintenance labor and supplies, supervision, payroll overhead, insurance, local taxation, and utilities. The indirect operating costs include technical and clerical labor, administrative costs, maintenance of facilities, and research.

All capital investments incurred prior to January 1969 (15 yr or more prior to the data of the analysis) are treated as sunk costs and ignored. The undepreciated balances of investments incurred since January 1969 are carried forward and entered as an expenditure in January 1984, the first year of the evaluation. All subsequent investments, reinvestments, operating costs, and transportation costs are expressed in constant January 1984 U.S. dollars. Reinvestments will vary according to capacity, length of production life, and age of the facilities.

After production parameters and costs for the development of the iron ore deposits were established, the Bureau's supply analysis model (SAM) (*11*) was used to perform various economic evaluations pertaining to the availability of iron ore. The SAM system is an economic evaluation simulator that is used to determine the constant-dollar long-run price at which the primary commodity must be sold to recover all costs of production, including a prespecified DCFROR on investment; in other words, the price determined is the average long-run total cost of production for each operation over its entire producing life. The DCFROR is defined as the rate that makes the present value of all current and future revenues equal to the present value of all current and future costs of production. For this study a constant 15-pct DCFROR on investment was specified.

The SAM system contains a separate tax records file for each State and foreign country that includes all the relevant tax parameters under which a mining firm would operate. These tax parameters are applied to each mineral deposit under evaluation with the implicit assumption that each deposit represents a separate corporate entity, with negative cash flows in the developmental stages carried for-

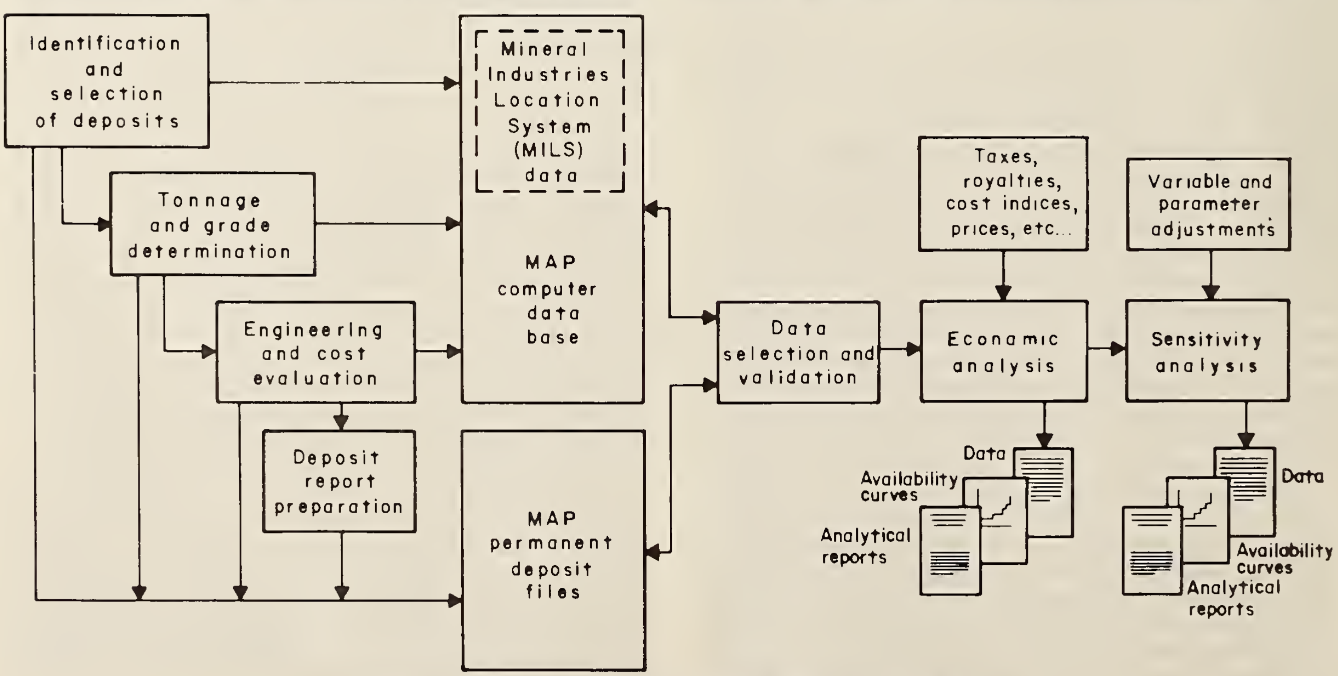

Figure 4.—Minerals Availability program evaluation procedure.

ward over time as tax losses (where allowed) rather than being applied against other possible corporate revenues in the year they occur. Other costs in the analyses include standard deductibles such as depreciation, depletion, deferred expenses, and investment tax credits. The SAM system also contains a separate file of economic indexes to allow for updating of all cost estimates for producing, developing, and nonproducing deposits.

Detailed cash-flow analyses are generated with the SAM system for each preproduction and production year of a mine or deposit, beginning with the initial year of analysis (1984). Upon completion of the individual analyses for each deposit, all properties were simultaneously analyzed and aggregated into availability curves.

The potential availability of the iron ore products recoverable from a deposit is presented graphically as a function of the total cost of production (defined as the constant-dollar long-run price necessary to recover all production costs and the specified rate of return) associated with that deposit. Availability curves are constructed as aggregations of the total amount of product potentially available from each of the evaluated operations, arranged in order from the deposits having the lowest average total cost per unit of production to those having the highest. The potential available quantity of the iron ore product at a particular market price can be seen by comparing that price with the derived average total cost values shown on the availability curves. The total recoverable tonnage potentially available at or below a particular market price can be read directly from the curve.

For this study, all iron ore products were assigned to one of four general categories: lump ore, sinter fines, pellet feed, and pellets. Shown in table 6 are the products with sizes and commodity prices assumed for each. When there is more than one product available from each mine, the total

Table 6.—Iron ore products, sizes, and commodity prices

Product	Size	Commodity price, $/Fe unit
Lump ore	Plus 1/4-in.	0.32
Sinter fines	Minus 1/4-in plus 100 mesh	.28
Pellet feed	Minus 100 mesh	.30
Pellets	Minus 20 plus 10 mm	.42

cost reflects the required prices for each product. "Price proportioning" is utilized to allow for the total cost of production to be allocated among all products rather than one, especially in operations for which there is not a clearly defined primary product. Each product at each operation is assigned a commodity price, shown in table 6. The ratio of the price or the price proportion of one product to another, e.g., of lump ore to sinter fines, has been approximately the same over the last few years and was assumed to remain constant in the future. For example, prices for sinter fines have been approximately 88 pct of the price of lump ore and are assumed to remain at this level.

The total necessary revenues for each property were determined, and then allocated to each product of that operation. For example, a property producing 5 Mmt/yr of lump ore grading 66 pct Fe and 3 Mmt/yr of sinter fines grading 64 pct Fe per year would receive 66 pct of its revenues from the lump ore and 34 pct from the sinter fines.[4]

Hence, the availability curves show the price required or total cost for each product from each mine, because many of the mines produce more than one product.

Certain assumptions are inherent in the availability curves. First, all undeveloped deposits will produce at full design capacity throughout their proposed productive lives. Second, each operation will be able to sell all of its output at the determined total cost and obtain at least the minimim specified rate of return. Third, all preproduction development of all undeveloped deposits began in January 1984.

EVALUATED IRON ORE RESOURCES

According to Bureau statistics, world iron ore resources are estimated to exceed 800 billion lt of crude ore and contain more than 260 billion st Fe (*1*). Evaluated in this study are demonstrated iron ore resources of 75.3 billion lt containing 29.8 billion lt recoverable Fe. Forty-three domestic deposits containing 9.5 billion lt of iron ore and 86 foreign deposits containing 20.3 billion lt of iron ore were evaluated in this study. Table 7 shows the properties evaluated in this study with resource and other pertinent deposit information.

The selection criterion used for the domestic iron ore deposits for inclusion in this study was a minimum of 2 MMlt of in situ contained iron. Because of the magnitude of the number of other known deposits in the MEC's, no single criterion was used for deciding whether or not a particular mine or deposit was to be included in this study. Consideration was given to large mines currently in production, particularly in the export market, deposits for which production plans have been announced, and deposits important to an individual country's economy, including those that have a chance of being developed in the foreseeable future. The selection criterion is admittedly subjective for the United States as well as for foreign properties. A strict adherence to selection criteria based on contained iron data would have omitted some of the mines presently important to the world market while including deposits that have no potential development based on political considerations and good business sense.

The resource data for the deposits evaluated for this study have been collected from many sources, both published and unpublished. It is the intention of the Bureau to evaluate individual deposit resources at the demonstrated level according to the definition established by the Bureau of Mines and the U.S. Geological Survey, as shown in figure 5. This corresponds roughly to the proven plus probable levels normally used by industry. Some sources, however, have used the term "reserves" in a general sense and have included either proven reserves only or have also included material in their reserve figures that is more accurately described as a part of potential ore. Some companies publish the same reserve figure continuously or for the entire company holdings and not on an individual deposit basis. Attempting to adjust these reserves for subsequent production introduces a degree of uncertainty because many of the

[4]Lump ore: 5 Mmt × 66 Fe units × $0.32/Fe unit = $105,600,000
Sinter fines: 3 Mmt × 64 Fe units × $0.28/Fe unit = $ 53,760,000
Total revenues $159,360,000
Portion of revenues:
Lump ore: $105,600,000/$159,360,000 = 66 pct
Sinter fines: $53,760,000/$159,360,000 = 34 pct

Table 7.—MEC iron ore deposit information and demonstrated resources used for analysis

Country, State, and property	Status[1]	Mining method[2]	Milling method[3]	Products[4]	In situ iron grade, pct	In situ tonnage, MMlt	Contained Fe, MMlt	Recoverable contained Fe, MMlt
Algeria:								
Gara Djebilet	E	S	M	S	51.8	969.4	502.1	421.6
Ouenza	P	S	S	PF,S	53.0	40.3	21.4	15.8
Total or wtd av					51.9	1,009.7	523.5	437.4
Australia:								
Deepdale	E	S	S	S	57.2	984.2	563.0	550.9
Giles Mountain	E	S	S	S	63.6	295.3	187.8	183.7
Koodaideri	E	S	S	S	61.7	711.6	439.1	429.8
Marandoo	E	S	S	L,S	62.1	339.2	210.6	197.0
Marillana	E	S	S	S	59.7	738.1	440.6	431.2
McCamey's Monster	E	S	S	S,L	62.4	246.4	153.8	150.4
Middleback Range	P	S	S	L,P,S	63.7	75.5	48.1	47.0
Mining Area C	E	S	S	S	62.2	440.0	273.7	201.5
Mount Brockman	E	S	S	S	62.2	393.7	244.9	235.7
Mount Tom Price	P	S	M	L,P,S	61.9	640.2	396.3	278.6
Mount Whaleback	P	S	S	S,L	61.4	1,653.0	1,014.9	960.8
Nammuldi	E	S	S	S	62.5	206.7	129.2	126.4
Paraburdoo	P	S	S	S,L	63.4	444.3	281.7	275.4
Rhodes Ridge	E	S	S	S	61.8	984.2	608.2	587.8
Robe River	P	S	S	P,S	57.0	138.4	78.9	78.9
Savage River	P	S	M	P	35.0	85.6	30.0	22.1
TR5585	E	S	S	S	62.2	206.7	128.6	125.8
West Angelas	E	S	S	S	62.2	314.2	195.4	187.6
Wittenoom	E	S	S	S	54.9	984.2	540.3	529.0
Yandicoogina	E	S	S	S	58.5	1,223.4	715.7	671.3
Total or wtd av					60.1	11,104.9	6,680.8	6,270.9
Brazil:								
Aguas Claras	P	S	S	PF,L,S	62.2	254.6	158.4	148.4
Alegria	P	S	S	L,S	63.5	171.1	108.6	103.8
Andrade	P	S	S	L,S	65.2	85.1	55.5	54.3
Capanema	P	S	S	L,S,P	61.2	176.4	108.0	105.7
Carajas	E	S	S	PF,L,S	66.1	1,319.8	872.4	815.9
Casa de Pedra	P	S	S	L,S	63.7	237.9	151.5	92.1
Caue	P	S	M	L,P,S	56.1	611.6	343.1	317.5
Conceicao-Dos Corregos	P	S	HMS	S,P,L	66.6	1,033.5	688.3	637.9
Corregos do Feijao	P	S	S	S,PF,L	64.7	102.5	66.3	61.6
Fabrika-Joao Pereira	P	S	M	S,L,P	62.5	256.7	160.4	94.7
Mutuca	P	S	S	S,L	63.7	59.0	37.6	36.7
Periquito	P	S	S	L,S	66.6	151.1	100.6	98.5
Samarco	P	S	F	PF,P	53.2	351.7	187.1	168.5
Tamandua	E	S	S	PF,L,S	63.8	274.6	175.2	164.5
Timbopeba	P	S	S	S,L	66.6	167.3	111.4	109.6
Total or wtd av					63.3	5,252.9	3,324.4	3,009.7
Cameroon: Les Mamelles	E	S	F	P	30.1	196.8	59.2	49.8
Canada:								
Carol Lake	P	S	S	S,P	37.6	1,733.3	651.7	275.0
Fire Lake	P	S	S	P	38.0	352.3	133.9	107.1
Mount Wright	P	S	S	S	31.4	2,471.6	776.1	645.3
Wabush	P	S	M	P	36.0	1,691.9	609.1	233.1
Total or wtd av					34.7	6,249.1	2,170.8	1,260.5
Chile:								
El Algarrobo	P	S	M	S,L,P	54.0	63.0	34.0	27.8
El Romeral	P	S	M	S,L	55.0	78.0	42.9	38.4
Total or wtd av					54.5	141.0	76.9	66.2
Gabon: Belinga	E	S	S	S	63.9	506.9	323.9	237.7
Guinea:								
Mount Nimba	E	S	S	S	66.7	344.5	229.8	206.8
Simandou	E	S	S	PF,L,S	63.1	590.5	372.6	363.0
Total or wtd av					64.4	935.0	602.4	569.8
India:								
Bailadila # 5	P	S	S	S,L	64.4	206.2	137.8	112.5
Bailadila # 14	P	S	S	S,L	66.9	76.3	51.0	42.8
Bolani	P	S	S	S,L	58.9	471.8	277.9	66.0
Kudremukh	P	S	F	PF,P	38.1	636.6	242.5	144.8
Zone D	P	S	S	S,L	60.8	199.7	121.4	111.4
Total or wtd av					52.2	1,590.6	830.6	477.5
Ivory Coast: Mount Klahoyo	E	S	M	P	35.7	659.4	235.4	208.7
Liberia:								
Bea Mountain	E	S	M	S	41.8	120.9	50.5	18.4
Bong	P	S	M	S,P	37.1	262.4	97.4	84.9
Mano River	PP	S	S	S	51.5	79.6	41.0	25.5
Nimba	P	S	F	PF,P,S	59.1	61.1	36.1	21.8
Western Area	P	S	M	S	52.2	405.0	211.4	160.5
Wologisi	E	S	M	S	32.7	812.0	265.5	199.7
Total or wtd av					40.3	1,741.0	701.9	510.8
Libya: Wadi Shatti	E	S	S	S	51.4	782.4	402.2	393.5
Mauritania:								
F'Derik	P	S	S	S	64.5	130.7	84.3	76.3
Guelbs	E	S	M	S,PF	36.8	380.0	139.8	104.3
Total or wtd av					43.9	510.7	224.1	180.6

See footnotes at end of table.

Table 7.—MEC iron ore deposit information and demonstrated resources used for analysis—Continued

Country, State, and property	Status[1]	Mining method[2]	Milling method[3]	Products[4]	In situ iron grade, pct	In situ tonnage, MMlt	Contained Fe, MMlt	Recoverable contained Fe, MMlt
Mexico:								
El Encino-Aquila	P	S	M	L,P	36.4	88.1	32.1	24.0
La Perla	P	S	M	P,L	50.7	41.0	20.8	13.2
Las Hercules	P	S	F	P	58.3	98.0	57.1	28.4
Las Truchas-Ferrotepec	P	S	M	P	48.8	106.3	51.9	37.7
Pena Colorado	P	S	M	P	37.7	130.7	49.3	43.8
Total or wtd av					45.5	464.1	211.2	147.1
New Zealand: Waipipi	P	D	G	S	15.5	271.2	42.0	33.9
Norway: Sydvaranger	P	S	P	P	32.6	187.3	61.1	51.8
Peru: Marcona	P	S	M	PF,P,S	53.5	1,433.3	766.8	644.7
Portugal: Moncorvo	E	S	M	P	37.0	243.7	90.2	52.2
Senegal: Faleme Area	E	S	S	S,L	63.6	334.6	212.8	170.8
Sierra Leone: Marampa	P	S	G	S	32.3	57.1	18.4	15.0
Sourth Africa, Republic of:								
Sishen	P	S	HMS	S,L	64.0	1,293.8	828.0	656.5
Spain: Marquesado	P	S	S	S,L	53.7	33.9	18.2	16.7
Sweden:								
Kiruna	P	U	M	P,S,L	49.2	1,584.3	779.5	746.7
Malmberget	P	U	M	P,S	40.4	211.6	85.5	80.2
Svappavaara	P	S	S	P,L	45.0	233.2	104.9	84.5
Total or wtd av					47.8	2,029.1	969.9	911.4
United States:								
Alabama:								
Big Sandy Area	PC	U	H	P	35.2	24.4	8.6	6.7
Birmingham District	PC 1971	U	H	P	34.9	1,061.0	370.3	58.2
Southeast Alabama District	PC	S	H	P	26.4	258.9	68.3	7.3
Total or wtd av					33.3	1,344.3	447.2	72.2
Alaska:								
Klukwan	E	S	M	P	10.8	883.5	95.4	72.3
Port Snettisham	E	S	M	S	18.9	530.0	100.2	65.1
Total or wtd av					13.8	1,413.5	195.6	137.4
California: Eagle Mountain	PC 1982	S	H	P	33.4	339.5	113.4	83.1
Michigan:								
Cascade Reserves	PC	S	H	P	34.2	1,377.9	471.2	107.4
Empire Mine	PT	S	M	P	31.5	1,233.1	388.4	231.1
Groveland Mine	PC 1982	S	M	P	35.1	101.8	35.7	26.2
Republic Mines	TC 1981	S	F	P	34.2	39.8	13.6	13.6
Tilden Mine	PT	S	F	P	33.3	854.1	284.4	190.6
Total or wtd av					33.1	3,606.7	1,193.3	568.9
Minnesota:								
Butler Taconite	PC 1985	S	M	P	32.0	99.5	31.8	17.7
Erie Mine	PT	S	M	P	31.7	1,464.1	464.1	345.4
Hibbing Taconite	PT	S	M	P	30.7	1,038.1	318.7	197.2
Magnetic Taconites[5]	E	S	M	P	[6]21.6	17,319.5	3,741.0	3,366.9
Minntac Mine	PT	S	H	P	[6]22.0	1,700.7	389.6	331.6
Minorca Mine	PT	S	M	P	[6]21.0	264.0	55.4	52.6
National Steel	PT	S	M	P	31.0	965.9	299.4	172.0
Peter Mitchell	PT	S	M	P	[6]23.5	1,109.4	260.7	233.6
Thunderbird north and South	PT	S	MP	P	32.3	1,205.0	389.2	261.4
Total or wtd av					[6]23.6	25,166.2	5,949.9	4,978.4
Missouri:								
Bourbon Deposit	PP	U	M	P	30.4	178.6	54.3	35.0
Camels Hump	PP	U	M	P	36.6	22.3	8.2	5.8
Pea Ridge	PT	U	M	PF	57.0	129.3	73.7	66.5
Total or wtd av					41.3	330.2	136.2	107.3
Montana:								
Black Butte	E	S	M	P	22.2	137.9	30.6	25.4
Carter Creek Iron	E	S	M	P	30.0	74.6	22.4	17.9
Copper Mountain	E	S	M	P	27.8	27.3	7.6	6.1
Total or wtd av					25.3	239.8	60.6	49.4
Nevada:								
Buena Vista	E	S	M	P	19.0	140.7	26.7	23.4
Dayton Iron Deposit	E	S	P	P	42.0	40.4	17.0	14.6
Modarelli Mine	E	S	H	P	51.8	26.1	13.5	12.4
Pumpkin Hollow	E	S	M	P	26.7	178.1	47.6	42.3
Total or wtd av					27.2	385.3	104.8	92.7
New Jersey: Mount Hope Iron Mine	PC	U	M	S	38.4	4.5	1.7	3.0
New York:								
Benson Mines	PC 1978	S	M	P	23.5	181.0	42.5	29.8
Mineville Mines	PC 1971	U	M	P	42.0	90.0	37.8	25.5
Total or wtd av					29.6	271.0	80.3	55.3
Texas: Lone Star Deposits	PC 1984	S	H	S	27.0	76.9	20.8	12.4
Utah:								
McCahill Orebody	PC	S	M	P	52.5	49.2	25.8	23.3
Rex Orebody	E	S	M	P	52.5	150.0	78.8	70.9
Total or wtd av					52.5	199.2	104.6	94.2

See footnotes at end of table.

Table 7.—MEC iron ore deposit information and demonstrated resources used for analysis—Continued

Country, State, and property	Status[1]	Mining method[2]	Milling method[3]	Products[4]	In situ iron grade, pct	In situ tonnage, MMlt	Contained Fe, MMlt	Recoverable contained Fe, MMlt
United States—Con.								
Wisconsin:								
Agenda Deposit	E	S	M	P	[6]25.5	157.5	40.2	29.2
Black River Falls	PC 1983	S	M	P	30.0	14.5	4.4	3.2
Gogebic Deposit	E	S	M	P	31.0	778.5	233.6	149.1
Penokee Deposits#1 and #2	E	S	M	P	33.4	2,257.7	754.1	476.8
Pine Lake Taconite	E	S	M	P	[6]23.0	202.7	46.6	36.4
South Butternut	E	S	M	P	[6]25.9	52.2	13.5	9.8
Total or wtd av					31.5	3,463.1	1,092.4	704.5
Wyoming: Atlantic City	PC 1984	S	M	P	26.1	69.6	18.2	16.0
Total or wtd av, United States					25.6	36,909.8	9,519.0	6,974.8
Venezuela:								
Altamira	P	S	S	P,L,S	63.1	128.6	81.1	68.7
Cerro Arimagua	E	S	S	PF,L,S	62.2	133.9	83.3	82.4
Cerro Bolivar	P	S	S	PF,L,S	63.1	184.7	116.5	112.8
Cerro Redondo	E	S	S	P,L,S	61.1	162.4	99.2	96.2
El Pao	P	S	W	S,L	63.1	34.3	21.6	20.6
El Trueno	E	S	S	PF,L,S	61.1	108.3	66.2	64.1
Los Barrancos	E	S	S	PF,L,S	63.1	228.3	144.1	139.6
San Isidro	P	S	S	S,PF,L	64.1	385.8	247.3	217.1
Total or wtd av					62.9	1,366.3	859.3	801.5
Grand total					NAp	75,304.6	29,753.0	24,149.5

[1]Status is as of January 1986 unless otherwise indicated. E, explored deposit; P, producer; PC, permanently closed; PP, past producer; PT, producing but with temporary closures; TC, temporarily closed.
[2]D, dredge; S, surface; U, underground.
[3]G, gravity separation; HMS, heavy medium separation; M, magnetic separation; P, pyrometallurgical processing; S, sizing; W, washing.
[4]L, lump ore; P, pellets; PF, pellet feed; S, sinter fines.
[5]Magnetic taconites in Minnesota contain subeconomic resources.
[6]These deposits are magnetic iron and not total iron, in which the iron content of the silicates and carbonates are not recovered.

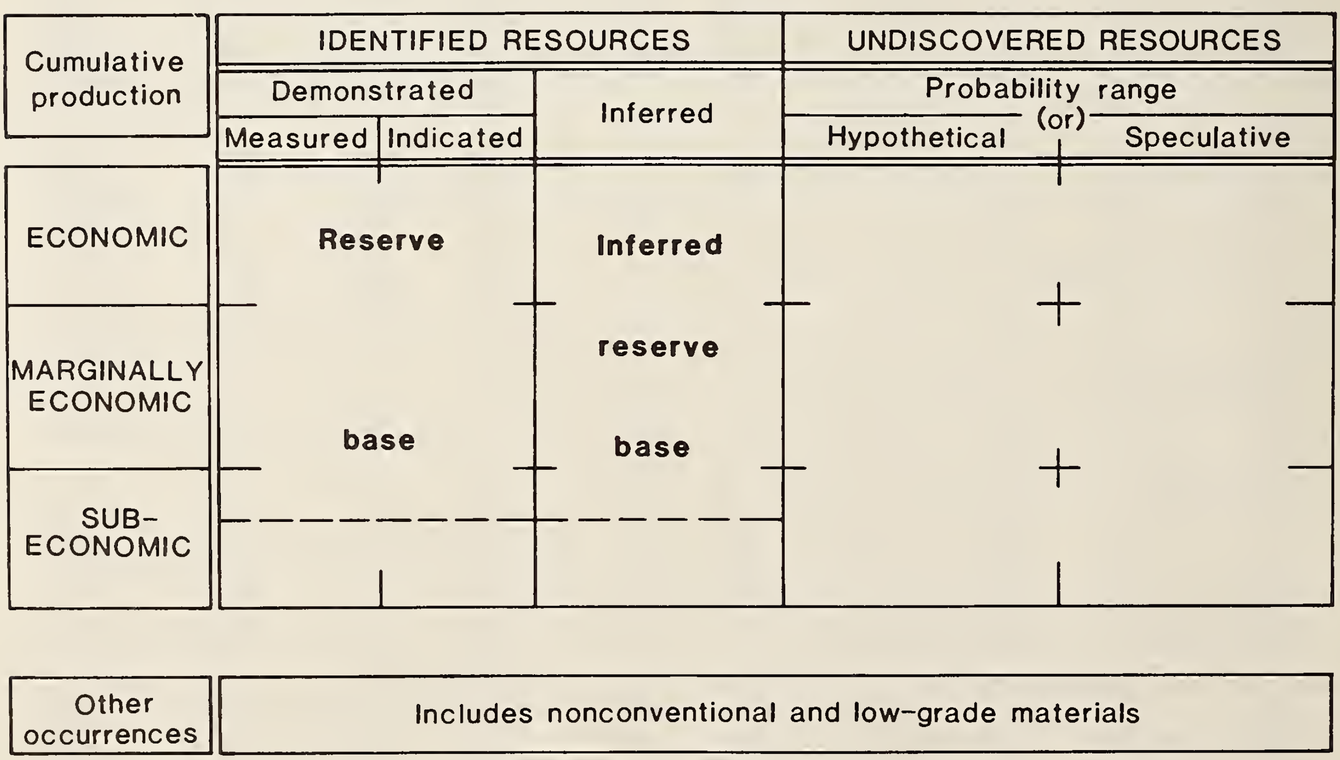

Figure 5.—Mineral resource classification categories.

published production data are in terms of finished product and not in terms of crude ore mined. The possibility also exists that additional reserves or resouces have been proven at these properties.

Resource numbers for Minnesota's Mesabi range are based on estimates made by Marsden (*12*). In table 7 the evaluated resources for Minnesota show a total of around 25 billion lt of in situ tonnage. Of this total around 8 billion lt are actual demonstrated resources, while the remaining 17 billion lt are magnetic taconites composed of several deposits in the Mesabi range. These deposits were evaluated on a range by range basis in the Marsden study, which includes subeconomic material.

COSTS

CAPITAL COSTS

Mining traditionally has been a capital-intensive industry with large investments required for planning and development. This is especially true for the iron ore industry. Iron ore is a bulk commodity of a low unit value that must be mined in large volumes. Factors affecting capital investments for iron ore include the size of the operation, the proposed locality, the necessary beneficiation facilities, and the infrastructure required to support the operation. Infrastructure includes rail lines, rolling stock, port facilities, and townsites. Infrastructure can account for 20 to 70 pct of the total capital investment required in a typical iron ore operation.

Two large mines are used as examples to illustrate the capital-intensive nature of iron ore mining. Shown in table 8 are capital cost estimates for mines in Australia and Brazil. While these mines have capacities greater than 35 Mmt/yr, smaller mines also require high expenditures. For example, a typical 3-Mmt/yr-capacity mine will require an estimated $175 million for initial investments. As illustrated in the table, the costs for plant and equipment are small in comparison to the costs of the infrastructure. The infrastructure costs range from 60 to 70 pct of total capital investments for these two large mines, with the railroad and rolling stock being a major component. A capital cost for a pelletizing plant is not included in this table, but an estimated cost for a 10-Mmt/yr plant is approximately $270 million.

Table 8.—Capital cost estimates for a large Australian and a large Brazilian iron ore mine

(Million 1984 dollars per metric ton)

Type of investment	Australia	Brazil
Capacity....................mt/yr...	46,000,000	35,000,000
Mine plant and equipment	344	208
Mill plant and equipment	36	146
Railroad	819	753
Rolling stock	205	211
Port	732	130
Townsite	504	102
Miscellaneous[1]	766	439
Total	3,406	1,989

[1]Miscellaneous costs include engineering, management fees, and administration.

OPERATING COSTS

The operating costs for the production of iron ore are discussed in this section. Table 9 shows operating cost

Table 9.—Operating cost ranges for selected MEC iron ore mines and deposits[1]

Country	Number of properties	Annual capacity, Mmt	Ore grade, pct	Operating costs, 1984 $/lt ore: Mine	Operating costs, 1984 $/lt ore: Beneficiation
Africa:					
Producers[2]	7	2.2–24.6	63–65	1.10– 3.40	0.60–2.30
Nonproducers[3]	12	4.5–25.2	56–67	1.80– 3.20	.90–3.80
Australia:					
Producers	5	2.7–45.0	57–65	1.60– 2.60	.30–1.60
Nonproducers	14	9.8–28.0	62–64	1.70– 3.60	.30– .50
Brazil: Producers	13	1.5–27.0	65–67	.70– 2.00	.50–1.70
Canada: Producers	3	17.4–43.8	66	2.00– 2.50	3.00–3.50
Europe: Producers[4]	5	1.3–17.7	50–70	2.60– 7.20	1.50–4.50
India: Producers	5	1.2–20.3	59–67	1.00– 5.00	.50–1.50
Mexico: Producers	5	2.0– 5.0	60–69	3.70– 6.50	1.90–3.00
Other South America:					
Producers[5]	7	3.8–14.8	61–67	1.90– 2.40	.90–2.70
Nonproducers[6]	4	4.5– 9.5	62–64	1.90– 2.10	W
United States:					
Lake Superior producers[7]	9	8.2–61.7	63–66	2.00– 4.50	3.25–5.00
Lake Superior nonproducers[8]	12	2.2–28.7	62–65	2.50– 4.50	3.50–9.00
Other nonproducers[9]	20	.7– 8.9	42–69	3.50–15.50	2.00–6.75

NAp Not applicable. W Withheld.
[1]Producers include presently producing mines; nonproducers include past producers, explored or developing deposits.
[2]African producers include Algeria, Liberia, Mauritania, Republic of South Africa, and Sierra Leone.
[3]African nonproducers include Algeria, Cameroon, Gabon, Libya, Ivory Coast, Liberia, Guinea, and Mauritania.
[4]European producers include Norway, Spain, and Sweden.
[5]Other South American producers include Chile, Peru, and Venezuela.
[6]Other South American nonproducers include Venezuela.
[7]Lake Superior producers include mines in the Mesabi and Marquette ranges.
[8]Lake Superior nonproducers include mines and deposits in the Mesabi, Marquette, and Gogebic ranges.
[9]Other nonproducers include California, Missouri, Montana, Nevada, New Jersey, New York, Texas, Utah, and Wyoming.

ranges for selected MEC iron ore mines and deposits. Costs are presented by country and by production status on a dollars per long ton of ore basis for mining and milling. In this evaluation, a producer is defined as any mine presently producing, while a nonproducer is defined as any past producer, explored deposit, or developing deposit.

Except in Sweden, iron ore mining is typically done by open pit methods. Mine operating costs per long ton typically range from $1.00 to $5.00 in all countries except in Europe, Mexico, and the domestic nonproducers. The mining costs in Europe are higher, because of high labor costs and the fact that Swedish mines are underground operations; high domestic mining costs may be attributed to energy and labor costs. The South American properties, including Brazil, have the lowest costs, $0.70/lt to $2.50/lt. The mining cost range for India is low, owing to the large Kudremukh project, another example of low labor costs.

Specific processing is required for different types of ore, and this impacts beneficiation costs. Some ores, specifically the taconites produced in the Lake Superior region and the hematites in Canada, require intense grinding, which results in higher energy expenses. As seen in table 9, these costs are higher and range between $3.25/lt and $5.00/lt. Beneficiation averages in other regions range from $0.30/lt to $4.50/lt. The ranges and averages for the Brazilian producer region tend to be low relative to the other regions in both the mining and beneficiation categories. This can be attributed not only to inexpensive labor costs but to the Carajas project, which has vast resources of ore that requires minimum beneficiation.

Pelletizing operating cost ranges are shown in table 10 for only those countries that have pellet production. Pelletizing is an energy-intensive operation directly related to the type of ore being processed. Magnetite ores are the least expensive to pelletize because an exothermic reaction created during the process minimizes the amount of fuel required. Hematite ores are more expensive, consuming approximately 85 pct more fuel on a per-ton basis than magnetite ores. The pelletizing costs for Canada are about twice those of the other regions because the ores mined are hematite, which results in higher fuel costs.

Table 10.—Pelletizing operating costs for selected MEC iron ore mines and deposits

Region or country	Operating costs, 1984 $/lt product
Brazil: Producers	12.30–13.00
Canada: Producers[1]	15.00–22.70
Europe: Producers	5.70– 8.90
Mexico: Producers	7.50–10.40
United States:	
Lake Superior producers	6.00–10.60
Lake Superior nonproducers	7.30–12.90
Other nonproducers	6.50–14.00

[1]Canadian producers include mines processing only hematite ores.

SHIPPING COSTS AND RATES

Internal iron ore transportation consists of the movement of iron ore or iron ore products to a steel plant. Sometimes the iron ore product is transported by truck to a nearby rail spur for shipment to a steel mill. Often the iron ore is transported directly by rail or barge to the steel mill or to a port for exportation. Some estimates of iron ore transportation rates are shown in table 11. Estimates similar to these were used in the study for various routes from the mine to final destination. The table illustrates that there is a correlation between length of haul and cost. The greater distance that ore is transported, the lower the cost is per metric ton-kilometer.

Table 11.—Estimates of rail transportation costs

Country	Cost range, 1984 $/mt·km	Distance range, km
Australia	0.003–0.004	50–430
Brazil	.005– .007	640–730
Canada	.008– .009	410–450
India	.020 (av)	60–470
Sweden	.038– .042	180–220
South Africa, Republic of	.005– .016	50–860
United States[1]	.005– .012	50–400

[1]Cost range for the United States is in dollars per metric ton-mile and distance is in miles.

The availability curves in this report are constructed on an f.o.b. port basis, because once the iron ore product reaches the port it is sold in several markets. Because many prices include the costs of shipping and handling, it is difficult to assess at the port how much of a product will be sold according to any specific price structure. Therefore, all products were taken to the port as a common reference point for the purpose of discussing availability.

During the past few years a variety of fluctuations in the shipping industry have caused freight rates to change accordingly. The freight rates do not reflect the actual costs required to operate the ship and recover capital investments. The shippers have had to remain competitive with each other and at times will contract rates that will not necessarily make a profit but will ensure some type of work. Therefore, combining an unstable industry with a

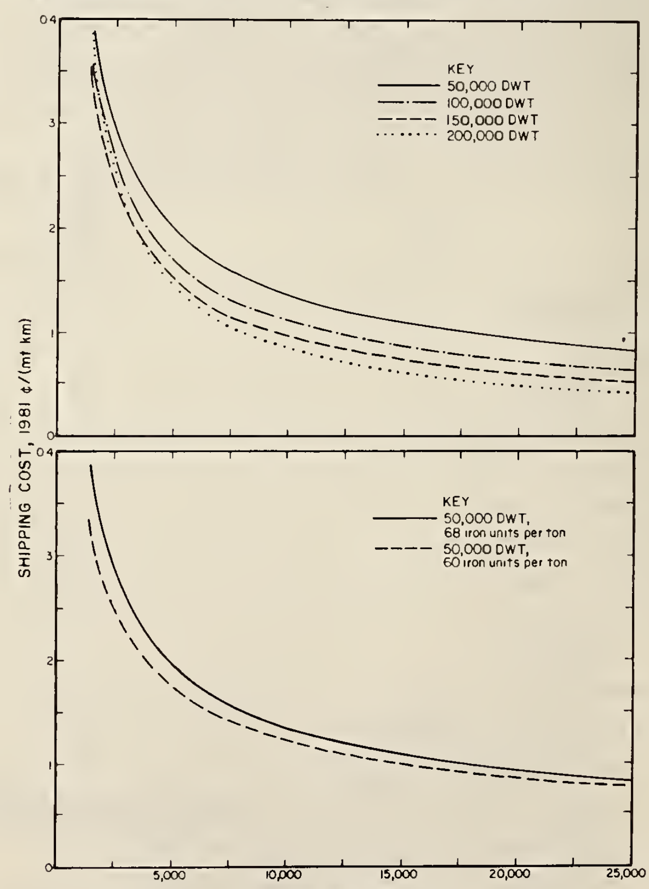

Figure 6.—Freight operating cost curves.

complex pricing system, it is difficult to assess the actual operating costs associated with the shipping of iron ore products on the international level.

As discussed in the International Transportation section of this report, several factors influence the actual operating costs of shipping. Several correlations with shipping costs exist, which involve the variables of distance, ship size, and ore grade. This is shown in figure 6, which illustrates freight operating costs at varying distances, deadweight tonnage, and iron content. These curves were developed by a linear regression of data provided under contract to the Bureau of Mines. This data set utilized 1981 costs, and because of the decline in the freight industry it does not correlate to present-day shipping operating costs and, therefore, freight rates. However, despite the actual costs, it illustrates that the greater the haulage distance and the larger the vessel, the lower the cost per iron unit.

For the availability analysis in this study, ocean freight costs were not used as analysis was made f.o.b. port. Table 12 shows 1984 ocean freight rates for spot charterings. From these rates it can be seen that ocean shipping accounts for a large portion of the final cost of iron. For example, in 1984 Australian producers had operating costs per long ton of ore ranging from $1.90 to $4.20 (table 12), and shipping a long ton of ore to the Republic of Korea would cost $5.00 to $6.00; thus, the shipping rates account for approximately 60 to 70 pct of the total cost.

Table 12.—Ranges of spot iron ore ocean freight rates, 1984

Origin	Destination	Ship size, 10^3 DWT	Rates, $/lt
Australia	Republic of Korea	100–150	$5.00–$6.00
	Western Europe	100–150	6.50– 8.75
Brazil	Japan	130–150	7.00– 9.00
		220	5.25– 6.00
	Western Europe	50– 65	5.75– 6.50
		80–155	4.50– 6.00
Eastern Canada	Japan	130–150	7.00– 9.00
	Western Europe	100–160	3.00– 4.25
Norway	Western Europe	90–100	1.75– 2.30

Source: Industrial Minerals.

AVAILABILITY OF IRON ORE PRODUCTS IN MARKET ECONOMY COUNTRIES

The economic viability of any given deposit is determined by the interrelationship of numerous factors. These factors consist of the inherent physical and chemical characteristics of the deposit such as the grade of ore, total resource, stripping ratio, type of ore, mining method, dilution, geology, and location. The financial aspects related to the operating and capital costs, annual capacity, transportation, tax structure, and numerous other considerations make up the total economic picture. The potential availability of MEC demonstrated resources of iron has been analyzed, considering the above factors, for each of the mines and deposits evaluated in this study. In this study a producer is defined as any mine presently producing, and a nonproducer is any past producing, explored, or developing deposit. The iron ore products evaluated are sinter fines, lump ore, pellets, and pellet feed.

ANNUAL AVAILABILITY

An annual curve shows the potential availability of total demonstrated resources at various total cost levels on an annual basis. The vertical axis represents total potential tonnage available; on the horizontal axis, time is represented in years for producers, and in the number of years following commencement of production for the nonproducers.

For a commodity such as iron ore, annual curves only emphasize the size of the resource. Therefore, they do not illustrate possible depleting resources that could be a detriment to a country that relies heavily upon the commodity. Also, annual curves represent potential annual production at full-capacity levels. Only annual curves for sinter fines are shown for illustration purposes. Producer and nonproducer annual availability curves for the other products are not shown as they tend to exhibit similar situations, thus illustrating the vast resources of tonnage available for each product. A summary of the potential annual availability of iron ore products analyzed in this study is shown in table 13.

Table 13.—Summary of annual availability of iron ore products

Product and status[1]	Reference price,[2] 1984 $/ltu	Tonnage available at total cost less than or equal to reference price,[3] MMlt: 1988 (N+4)	1992 (N+8)	1996 (N+12)	2000 (N+16)
Total sinter fines:					
Producers	0.25	165	142	120	85
Nonproducers	.25	26	38	52	63
Total lump ore:					
Producers	.25	60	60	56	56
Nonproducers	.25	NAp	5	12	15
Foreign pellets:					
Producers	.40	20	20	20	20
Nonproducers	.80	NAp	45	45	40
Domestic pellets:					
Producers	.80	44	44	44	44
Nonproducers	.80	9	9	9	9
Total pellet feed:					
Producers	.25	4	4	2	1.8
Nonproducers	.25	NAp	.7	2.0	2.6

NAp Not applicable.

[1]Annual availability for nonproducers is given assuming preproduction begins in 1984, or in year N, as illustrated for total sinter fines in figure 7. If preproduction began in a year other than 1984, the year of the annual tonnage would be adjusted accordingly by N+4, N+8, etc.

[2]Reference price is equivalent to various 1984 market prices in the international market.

[3]Total cost is in 1984 dollars determined at a 15-pct DCFROR.

The potential availability of sinter fines on an annual basis is shown in figure 7. This figure illustrates the total tonnage of sinter fines available annually at various cost levels. These curves represent producing and nonproducing mines at 100 pct capacity. The downward trend of the producer curves, beginning in 1990, shows a minor amount of depletion of resource due to annual production. Similarly, annual curves for the nonproducers show an increase in production for period of several "preproduction" years, attaining a level of full production and remaining constant until production begins to deplete the available resources. Preproduction is assumed to begin in year N for the nonproducer curves.

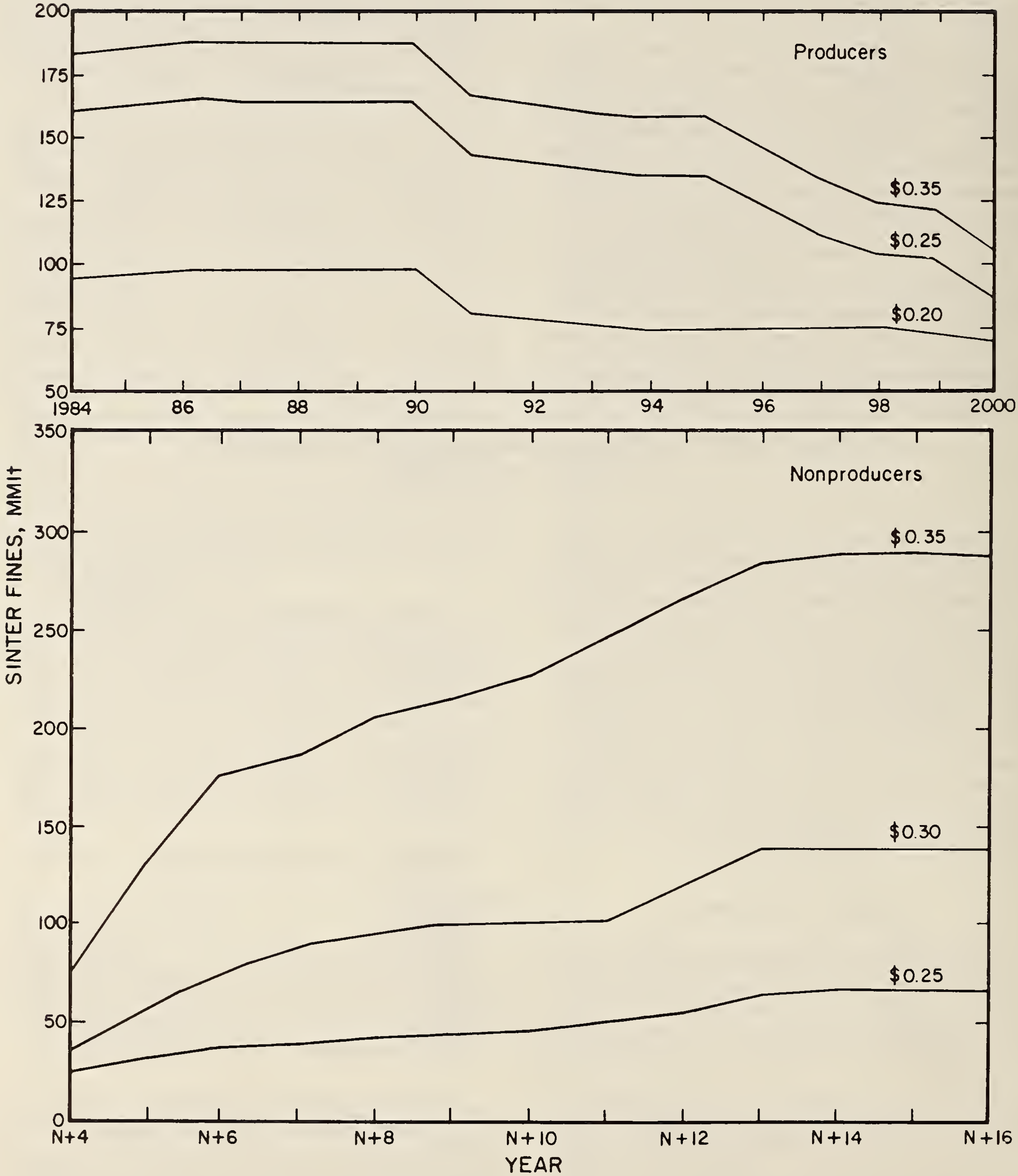

Figure 7.—Annual sinter fines availability for producers and nonproducers at various total costs, dollars per iron unit.

Table 13 shows similar trends over time for the other products. This table shows the availability of the various products on an annual basis at total costs that are less than or equal to a reference price, or market price. In the table, foreign and domestic pellets are shown separately because of differences in market pricing. The potential annual availability for the nonproducers is given assuming that preproduction begins in 1984. Preproduction may be assumed to begin in any other year designated as N, and the years that the annual tonnage is available should be adjusted accordingly.

TOTAL AVAILABILITY

Total availability curves are the representation of potentially recoverable tonnage of a resource that is represented graphically as a function of total cost of production over the life of the operation at a prespecified DCFROR. The curves represent the aggregation of the product that is potentially available from each evaluated deposit in order from the lowest total cost per unit of production to the highest. For this type of curve the tonnage is represented on the horizontal axis with the total cost on the vertical axis. From this, the total potential available tonnage of that product at a given market price can be derived by comparing that price with the total cost shown on the availability curves.

The iron ore products of sinter fines, lump ore, pellet feed, and pellets are sold on different price bases that vary by country, company, and contract. The availability curves in this study are presented on an f.o.b. basis, in which the total cost includes all costs required to take the iron ore product to the port. When market price is used to determine the potential total availability of an iron ore product, the reader must note that the curves in the study are f.o.b. port while the prices may be f.o.b. port, c.i.f., or c&f. (See Price Structure section of this report.) Therefore, ocean freight rates must be considered when c.i.f. or c&f prices are used.

The availability analysis determined that 18.6 billion lt of sinter fines, 4.9 billion lt of lump ore, 14.7 billion lt of pellets, and 820 MMlt of pellet feed are potentially available in MEC's.

Sinter Fines

There are approximately 18.6 billion lt of sinter fines potentially available from 73 of the 129 mines and deposits evaluated in this study. Of this total, approximately 61 pct is found in two countries—Australia and Brazil. Australia has 8.5 billion lt (46 pct), and Brazil has 2.7 billion lt (15 pct). Seventeen other countries have potentially available resources ranging from 4.5 MMlt in the United States to 970 MMlt in Canada.

Total availability of sinter fines from 73 properties at a 15-pct DCFROR, f.o.b. port, is shown in figure 8. Individual curves for 40 producers and 33 nonproducers are also shown in this figure. Of the 18.6 billion lt potentially available, 6.6 billion lt (35 pct) are from producers while

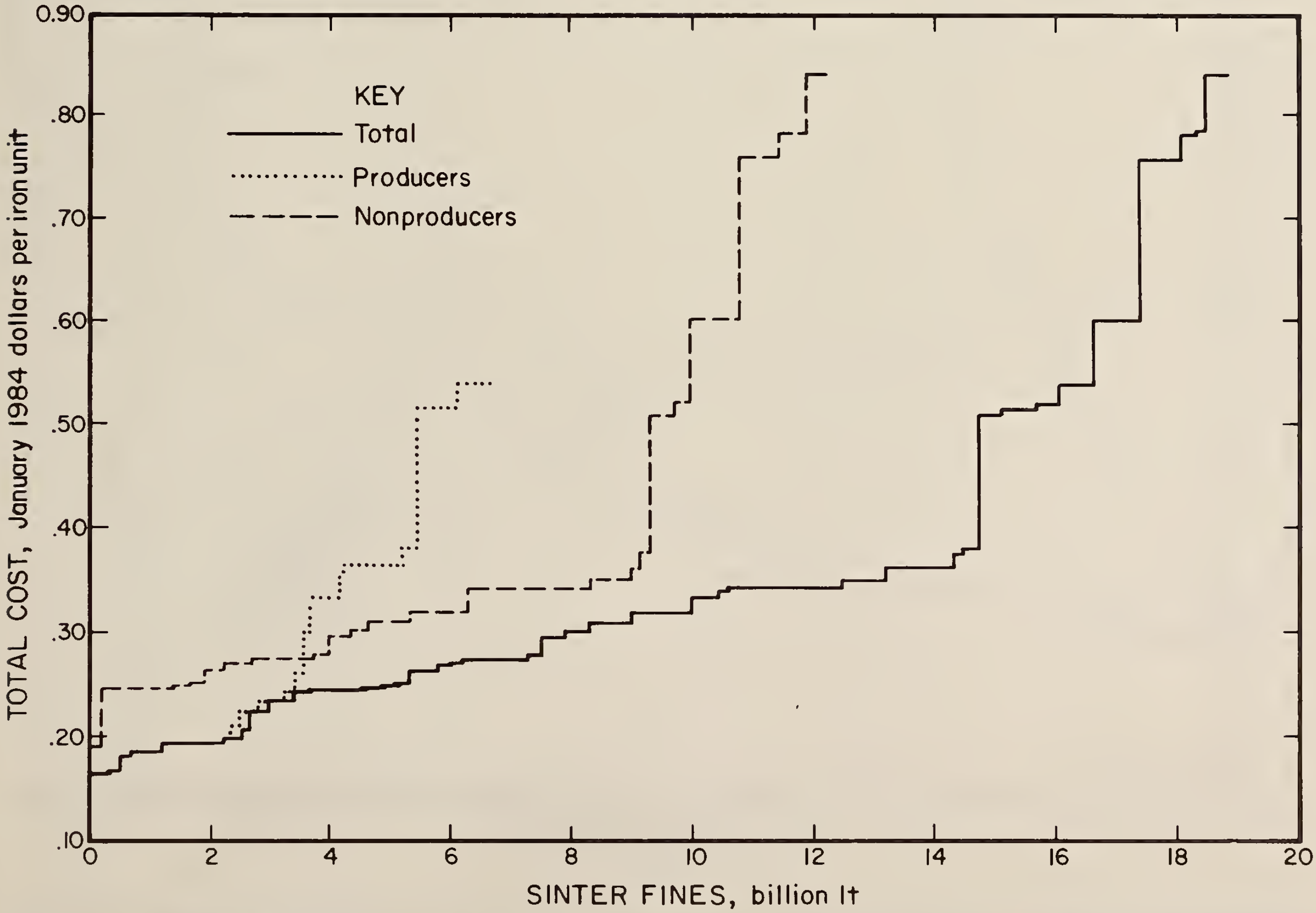

Figure 8.—Total potential sinter fines availability for producers and nonproducers in market economy countries at a 15-pct DCFROR.

12.0 billion lt (65 pct) are from nonproducers. The curves also show that up to 3.6 billion lt are available from producers for less than a total cost of $0.28 per iron unit.

The 1984 price for sinter fines on world markets ranged from $0.22 to $0.33 per iron unit. Therefore, at a total cost range of $0.22 to $0.33 there are approximately 2.9 to 10.4 billion lt of sinter fines potentially available at a 15-pct DCFROR, f.o.b. port. Availability of sinter fines for individual countries and regions at specific market prices is discussed in the Regional Availability of Iron Ore Products section of this report.

Lump Ore

There are approximately 4.9 billion lt of lump ore potentially available from 41 of the 129 mines and deposits evaluated in this study. Approximately 1.4 billion lt (29 pct) are available from Australia and 1.2 billion lt (25 pct) from Brazil. The remaining resources are from properties in eight countries with resources ranging from 10 to 500 MMlt.

Figure 9 shows the total potential availability of lump ore for 41 properties at a 15-pct DCFROR, f.o.b. port. Also illustrated are the individual curves for 30 producers and 11 nonproducers of lump ore. From the producers, a total of 3.7 billion lt (76 pct) are potentially available, and 1.2 billion lt (24 pct) are potentially available from the nonproducers. There are nearly 2.0 billion lt of lump ore potentially available from the producers at less than a total cost of $0.24 per iron unit, while at the same total cost there is 11 pct, or nearly 230 MMlt, potentially available from the nonproducers.

The market price for lump ore ranged from $0.26 to $0.32 per iron unit in 1984. At a 15-pct DCFROR there are approximately 2.2 billion to 3.0 billion lt of lump ore potentially available within a total cost range of $0.26 to $0.32 per iron unit, f.o.b. port. Lump ore availability for individual countries at specific market prices is discussed under Regional Availability of Iron Ore Products.

Pellets

Approximately 14.7 billion lt of pellets are potentially available from 71 of the 129 evaluated deposits. There are approximately 5.9 billion lt of pellets potentially available from 35 producers and 8.8 billion lt from 36 nonproducers.

Availability curves for the producers and nonproducers as a total are not shown because the foreign and domestic markets differ in pricing and the availability must be analyzed separately for each. Therefore, total curves with producer and nonproducer curves are shown for both domestic deposits and foreign deposits.

Figure 10*A* shows the total potential availability of pellets from foreign deposits only at a 15-pct DCFROR, f.o.b. port. The figure also shows the individual availability

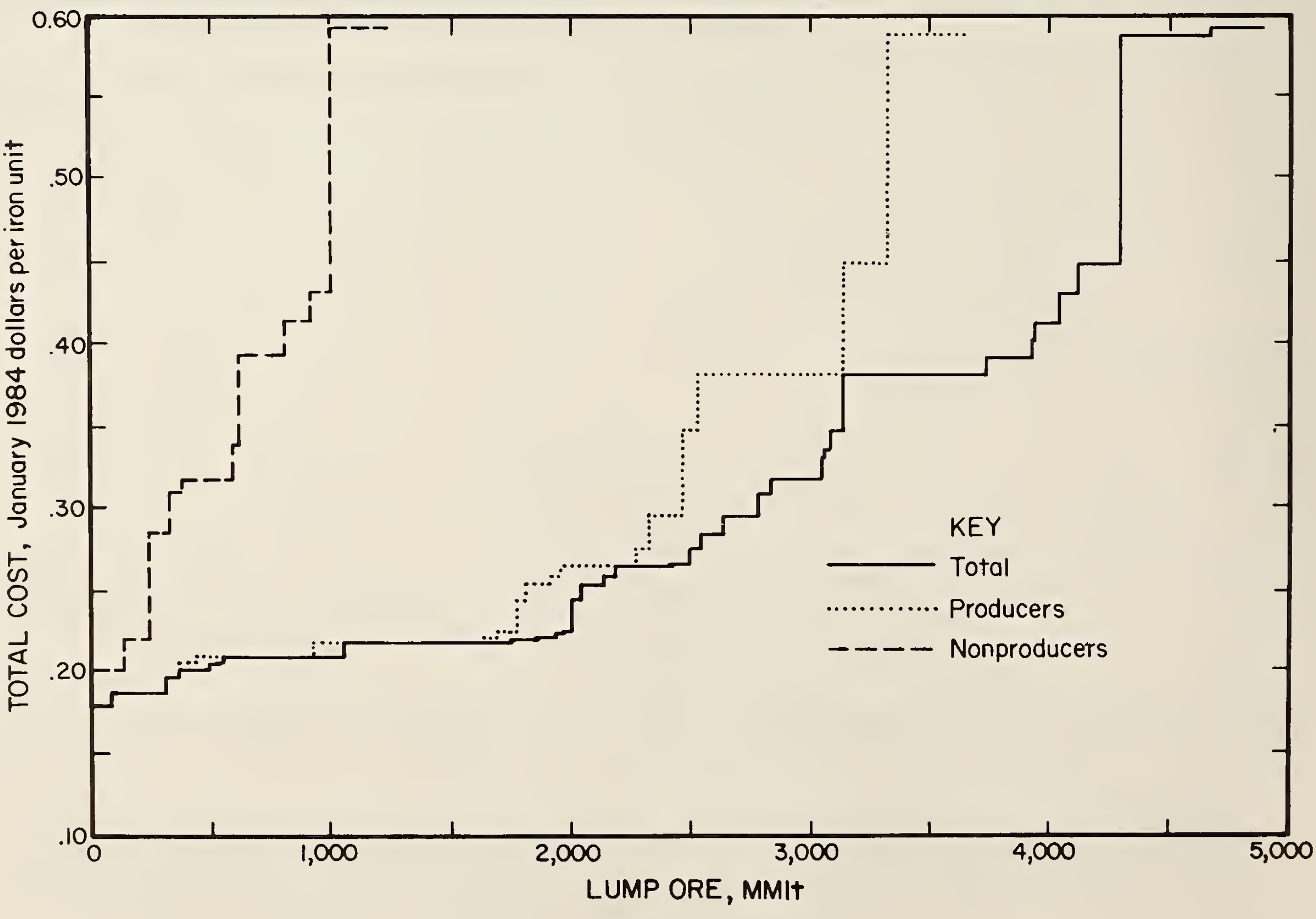

Figure 9.—Total potential lump ore availability for producers and nonproducers in market economy countries at a 15-pct DCFROR.

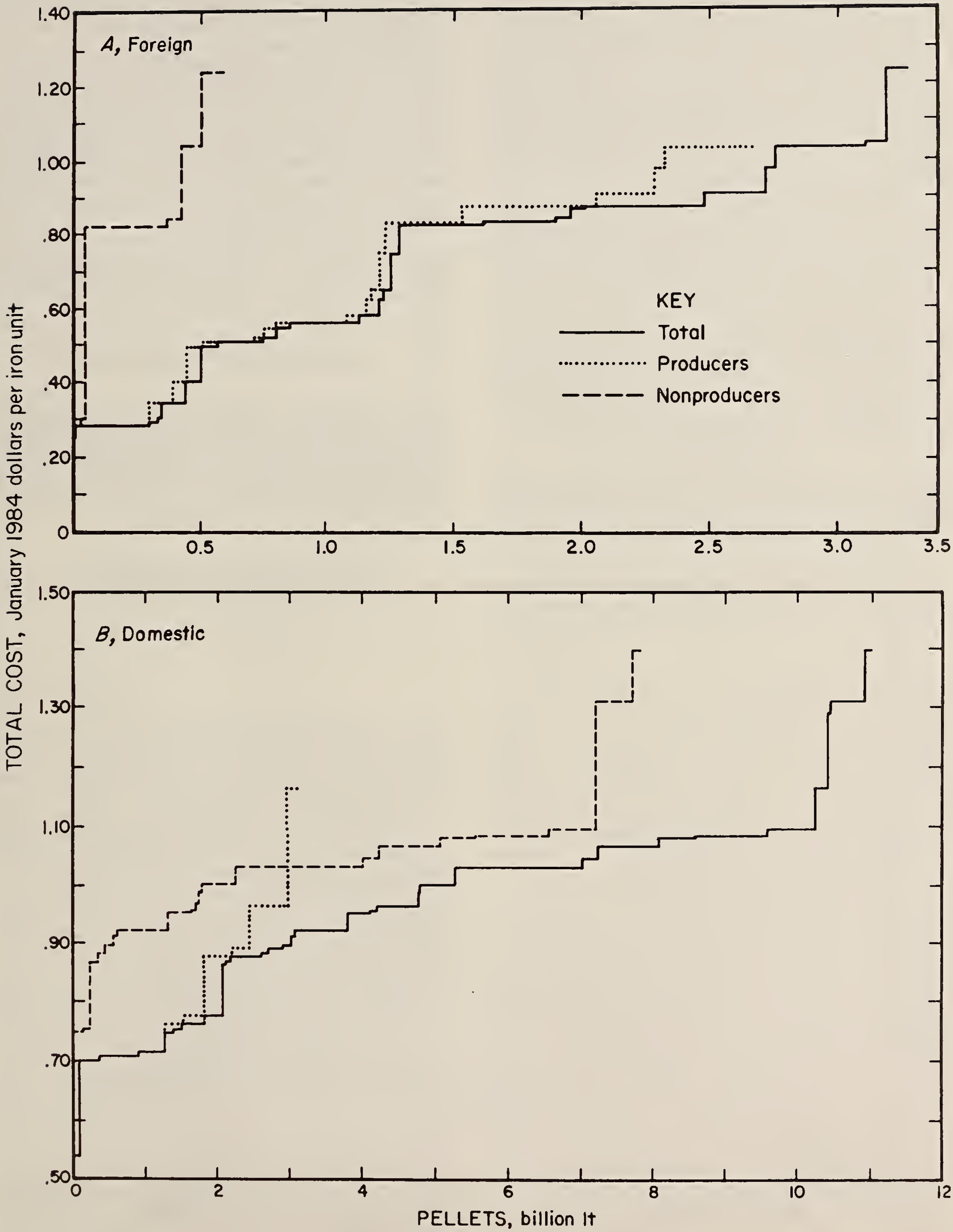

Figure 10.—Total potential pellet availability for producers and nonproducers in market economy countries at a 15-pct DCFROR.

curves for producers and nonproducers. From 25 producers there are 2.7 billion lt of pellets available, and from 6 nonproducers there are 588 MMlt available at a 15-pct DCFROR, f.o.b. port.

Market prices for pellets on the foreign market in 1984 ranged from $0.34 to $0.38 per iron unit, f.o.b. port. At these prices, approximately 350 to 440 MMlt of pellets are potentially available. The availability of pellets for individual foreign countries is discussed further under Regional Availability of Iron Ore Products.

The total potential availability of pellets from domestic deposits at a 15-pct DCFROR, f.o.b. port, is shown in figure 10*B*. Individual availability curves for producers and nonproducers are also shown. There are potentially 11.4 billion lt of pellets available, with 11 producers accounting for 3.2 billion lt (28 pct) and 30 nonproducers accounting for 8.2 billion lt (72 pct).

The 1984 domestic market price ranged from $0.80 to $0.86 per iron unit, f.o.b. port. At these prices, there are approximately 2.1 to 2.2 billion lt of pellets potentially available. The availability of domestic pellets is discussed further in Regional Availability of Iron Ore Products.

Pellet Feed

There are approximately 820 MMlt of pellet feed available from 17 evaluated mines and deposits. Of this total, approximately 312 MMlt (38 pct) are in Brazil and Venezuela, with another 168 MMlt (21 pct) in Peru and 133 MMlt (16 pct) in India.

Figure 11 illustrates the total potential availability of pellet feed along with individual availability of the producers and non-producers at a 15-pct DCFROR, f.o.b. port. The curves show that approximately 500 MMlt (61 pct) are potentially available from nine producers and 320 MMlt (39 pct) from eight nonproducers. The curves show that at a total cost less than $0.25 per iron unit 75 MMlt of pellet feed are potentially available from producers and nearly 100 MMlt from nonproducers.

Approximately 208 MMlt of pellet feed are potentially available from seven deposits in South America (three of which are producers) at a total cost less than $0.28 per iron unit, a typical 1984 market price for pellet feed, f.o.b. port.

Summary of Total Availability

A summary of the total availability of the four iron ore products analyzed in this study is shown in table 14. The table shows total potential availability with producer and nonproducer availability. Also, the potential tonnage available at total costs that are less than or equal to a reference price, or market price is given.

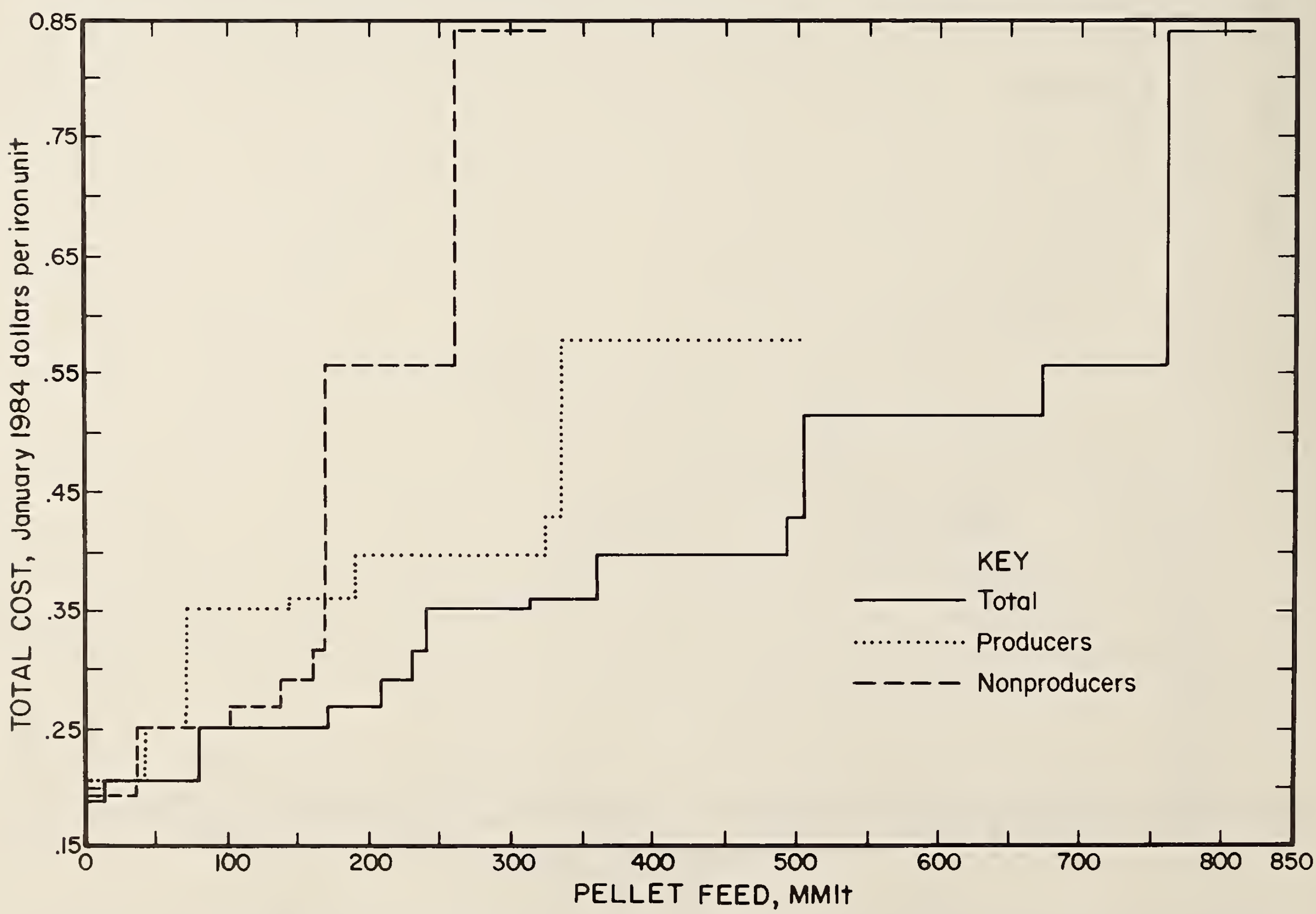

Figure 11.—Total potential pellet feed availability for producers and nonproducers in market economy countries at a 15-pct DCFROR.

Table 14.—Summary of total availability of iron ore products

Product and status	Number of properties	Total potential tonnage available, MMlt	Reference price,[1] $/ltu	Potential tonnage available at total cost less than or equal to reference price,[2] MMlt
Sinter fines:				
Producers	40	6.6	0.28	3.6
Nonproducers	33	12.0	.28	3.9
Total (fig. 8)	73	18.6	0.22– .33	2.9 –10.4
Lump ore:				
Producers	30	3.7	.24	2.0
Nonproducers	11	1.2	.24	.230
Total (fig. 9)	41	4.9	.26– .32	2.2 – 3.0
Foreign pellets:				
Producers	25	2.70	.34	.390
Nonproducers	6	.588	.34	.050
Total (fig. 10A)	31	3.3	.34– .38	.350– .440
Domestic pellets:				
Producers	11	3.2	.80	1.90
Nonproducers	30	8.2	.80	.260
Total (fig. 10B)	41	11.4	.80– .86	2.1 – 2.2
Pellet feed:				
Producers	9	0.500	.28	.070
Nonproducers	8	.320	.28	.140
Total (fig. 11)	17	.820	.28	.210

NAp Not applicable.

[1]Reference price is equivalent to various 1984 market prices in the international market.

[2]Total cost is in 1984 dollars determined at a 15-pct DCFROR.

REGIONAL AVAILABILITY OF IRON ORE PRODUCTS[5]

North America

United States

The iron resources of the United States are vast, whether measured in terms of tonnage of ore or in years of supply as compared with current annual consumption. The United States has an estimated resource of 108 billion lt of crude ore containing 30 billion st of Fe (*1*). U.S. resources are primarily low-grade taconite-type ores of the Lake Superior district that require beneficiation and agglomeration to make them suitable for commercial use.

The Lake Superior iron ore producing region is the most productive in the United States and includes parts of Minnesota, Michigan, and Wisconsin. This region is one of the world's major sources of iron ore and contains most of the known iron ore resources of the United States. Between 1891 and 1966 a total of 4.4 billon lt of iron ore was produced and shipped in the United States, with about 3.1 billion lt or 71 pct from the Lake Superior district. This has increased to over 95 pct in recent years.

Table 7 shows that a total of 36.9 billion lt of demonstrated resources in the United States were evaluated in this analysis. It should be noted that, of this total, the magnetic taconites in Minnesota contain subeconomic resources of 17.3 billion lt.

Other iron ore resources of the United States are widely distributed in several geographical regions. These are the Northeastern, Southeastern, Central-Gulf, Central-Western, and Western Regions, plus Alaska and Hawaii. Many of these areas no longer have producing mines and are considered as a resource only. Locations of some of the domestic deposits evaluated in this study are shown in figure 12.

The Lake Superior region includes the Mesabi, Cuyuna, Vermillion, and Fillmore "ranges" in Minnesota, the Black River Falls and Baraboo districts in Wisconsin, the Gogebic Range in Wisconsin and Michigan, and the Marquette and Menominee districts in Michigan. These districts contain the principal iron ore deposits in the region. It should be noted, however, that most of these districts are no longer producing iron ore owing to the depletion of direct shipping natural ore and the advent of the pelletization of the lower grade taconite ores. Many properties in these districts are considered exhausted and do not contain any marketable ore under current economic conditions. As of January 1986, 11 properties are producing pellets in the United States, including the underground Pea Ridge Mine in Missouri. (See table 7 for the operating status of the domestic mines evaluated in this study.) Locations of the Mesabi Range deposits evaluated in this study are shown in figure 13, and the deposits evaluated in Michigan and Wisconsin are shown in figure 14.

Minnesota and Michigan have installed pellet production capacities of 62.7 and 18.7 MMlt/yr, respectively. The global recession and lack of demand for U.S. steel products has forced temporary closures of pellet producers for periods ranging from 5 weeks to 4 yr. During the period 1979-83 the United States produced an average of 56.7 MMlt/yr pellets. Since this period included severe reductions in production, particularly in 1982 and 1983, it is not construed as being indicative of future levels of production.

Other iron ore products—e.g., run-of-mine ore, coarse ore, fine ore, and sinter fines—amounted to only 7.6 pct of all U.S. shipments during the past 5 yr and have diminished steadily to 5.2 pct of all shipments and 3.3 pct of production in 1983.

Since the late 1960's, pellets have been the primary blast furnace feed in the United States and Canada owing to the depletion of high-grade natural ores and construction of pellet plants at the mines. The dominant role of pellets in this region is one of the major factors that distinguishes this market from most other iron ore markets. The production of iron ore pellets, an excellent blast furnace feed, has made the low-grade taconite ore reserves of the Lake Superior district a major source of iron for the Nation's steel mills. In 1984, pellets made up 95.9 pct of all iron ore products produced in the United States (*2*).

Products from the iron ore mines in Minnesota and Michigan, and from most of the imports from Canada, are railed to docks on Lake Michigan, Lake Superior, or the Saint Lawrence River. Most of the loading docks are owned by the rail companies, which in turn are owned by the mining companies. As the shipping season generally runs from about April through December, because the lakes freeze in winter, there are large stockpiling and handling facilities at the docks where the pellets are stored during winter. From there, the pellets are shipped to docks on the lower Great Lakes nearest to the steel mills in Chicago, Cleveland, Detroit, and Pittsburgh. At the Lower Lake ports, the pellets are reloaded either into rail cars or into smaller boats capable of river navigation for the journey to the steel mills. This mode of water transportation for raw materials has enabled the heartland steel producers to retain a minor competitive edge over the other areas in the United States. Primarily due to the impact of transportation charges, iron ore from the Great Lakes area is not cost-competitive with overseas ores unloaded on the Gulf coast or the East Coast of the United States. These markets do not compete much with each other any more.

[5]Reserves and resources information that appears in this text but is not referenced was supplied by F.L. Klinger, Division of Ferrous Minerals, and other Bureau of Mines sources.

Figure 12.—Location map, United States deposits.

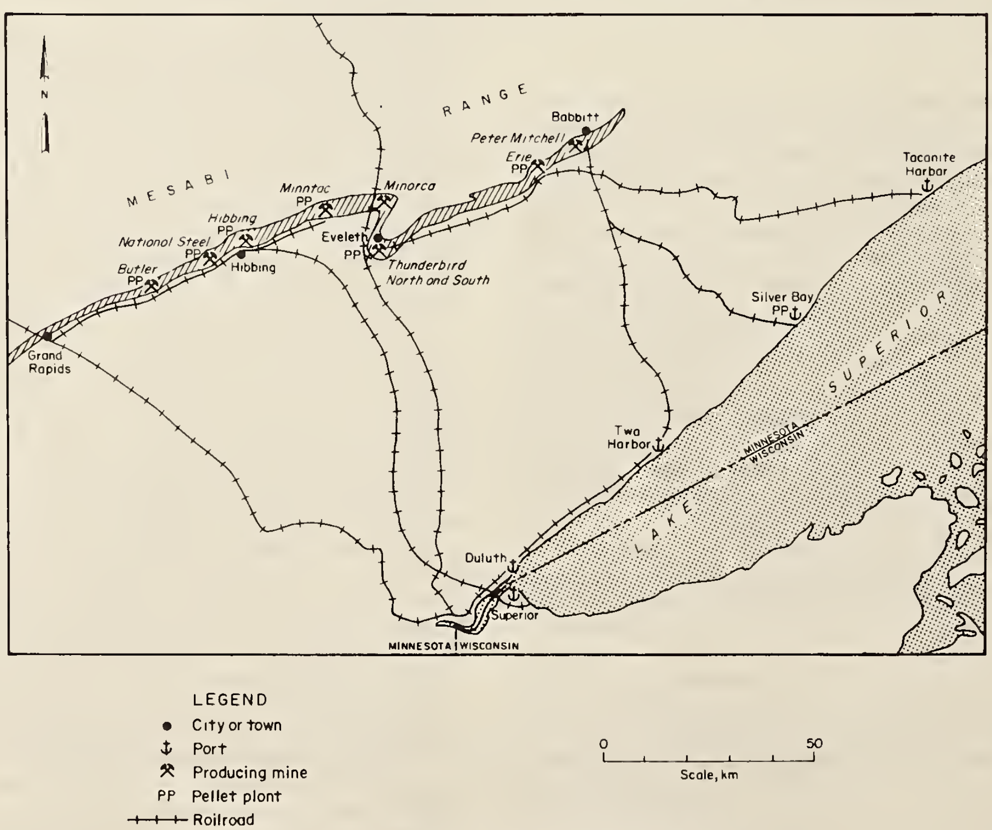

Figure 13.—Location map, Mesabi range deposits.

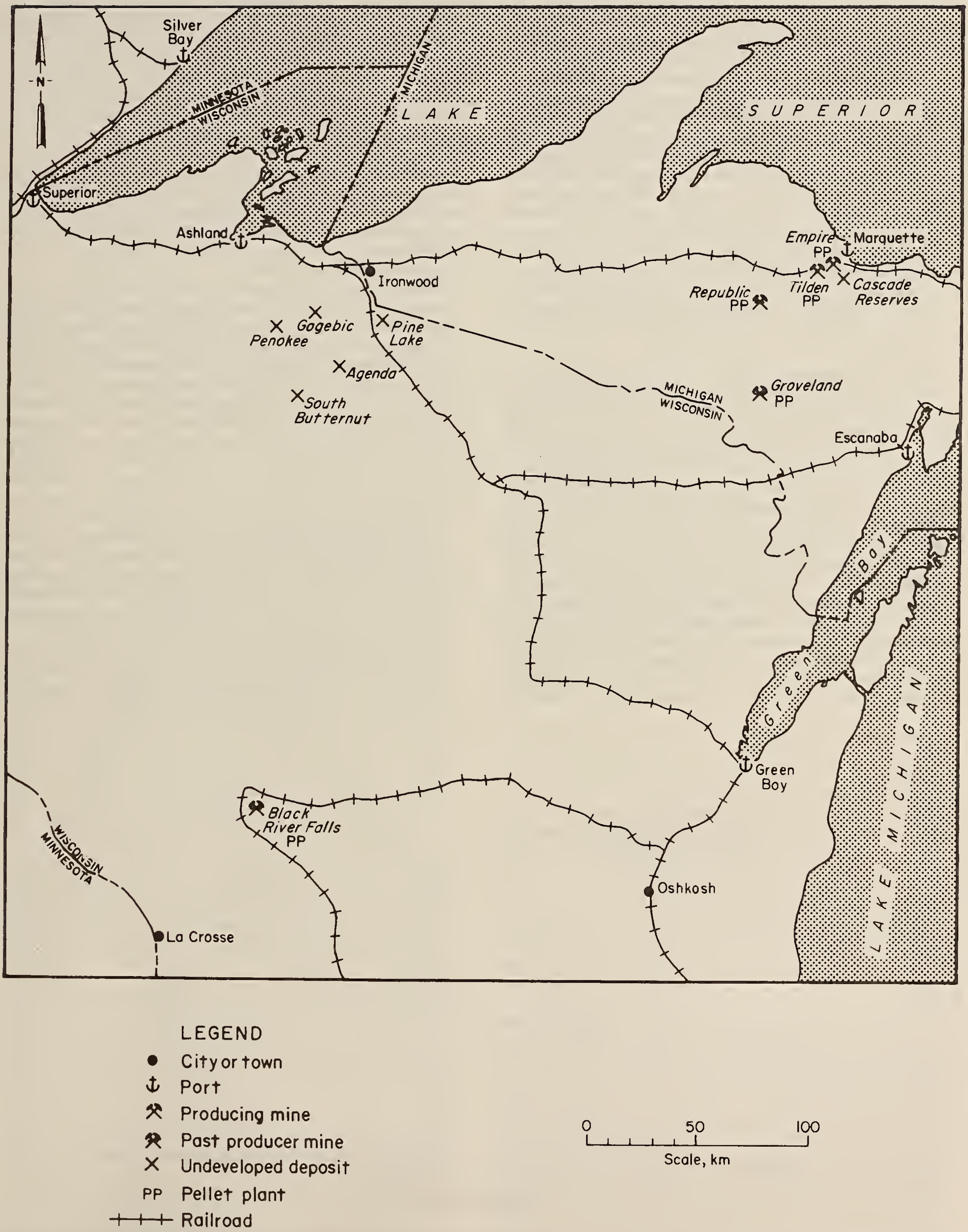

Figure 14.—Location map, Wisconsin and Michigan deposits.

Pellets are potentially available from 41 mines and deposits located in the United States, 30 of which are nonproducers. There are 11.4 billion lt of domestic pellets potentially available at a 15-pct DCFROR, f.o.b. port.

As discussed previously, the potential pellet availability of domestic producers and nonproducers is shown in figure 10*b*. Of the 11.4 billion lt potentially available, 11 producers account for 3.2 billion lt (28 pct) and 30 nonproducers for 8.2 billion lt (72 pct). The flat-lying portion of the nonproducer and total curves is mostly composed of the vast tonnages from the magnetic taconite resources in Minnesota. The 1984 domestic market price ranged from $0.80 to $0.86 per iron unit. Approximately 1.9 billion lt are potentially available from the producers and 260 MMlt from the nonproducers at a total cost less than or equal to $0.80 per iron unit. The producer curve shows that 1.3 billion lt are available at a total cost less than or equal to $0.72 per iron unit, hence less than the total costs of any of the nonproducers.

Figure 15 shows the potential availability of pellets from domestic iron ore surface mines presently in operation and mines permanently closed since 1981. Note that these curves represent operation at full production levels, while presently and in the recent past these iron ore mines have operated at much lower capacity levels. The producers consist of nine surface operations, seven in the Mesabi Iron Range and two in the Marquette Iron Range. There are approximately 3.0 billion lt of pellets available from the producers at a total cost less than $0.96 per iron unit. With 1984 market prices at $0.80 per iron unit, there are approximately 2.0 billion lt of pellets available at less than or equal to $0.80 per iron unit from producers and past producers.

The mines that have permanently closed since 1981 include one Menominee range mine (Groveland), one Mesabi range mine (Butler Taconite in Minnesota), one Wisconsin mine (Black River Falls in Wisconsin), and two Western U.S. mines (Eagle Mountain in California and Atlantic City in Wyoming). Also included in this category of permanently closed is one Marquette range mine (Republic in Michigan) that has been temporarily closed since 1981. These mines have approximately 320 MMlt available at total costs ranging between $0.75 and $1.06 per iron unit. With the past producers representing a small amount of available tonnage, an 11-pct reduction in the availability of pellet tonnage has occurred with the closures of these mines.

The availability of sinter fines in the United States is not shown graphically, because only three of the mines evaluated in this study have potential production. With the potential for nearly 120 MMlt, the total cost range for sinter fines is between $0.84 and $1.20 per iron unit, f.o.b. port, and accounts for less than 1 pct of the total potential sinter fines availability in MEC's.

The availability of domestic iron ore, as estimated in this report, is affected by several factors currently influencing the iron and steel industries in general. Demand for iron and steel has been depressed on a global basis for the last several years and in turn, the low demand for iron ore has been particularly harmful to the domestic iron ore industry. The U.S. iron ore industry continued to operate at less than 50 pct capacity in 1983, with most major mines being closed for part of the year. Despite low levels of production in 1982 and 1983, production of iron ore increased to 51 MMlt in 1984, or about 55 pct of capacity. Increased housing starts and an upturn in the auto industry have led to small gains in the demand for iron ore.

In 1984, the U.S. iron ore industry had a total mine production of 51 MMlt, of which about 98 pct was pelletized before shipment. The iron ore was produced by 17 companies operating 21 mines, 17 concentrating plants, and 11 pelletizing plants. The operations included 20 surface mines and 1 underground mine.

The effects of the recent recession on the domestic iron ore industry may be further compounded by the recent startup of the Carajas project in Brazil. Should port restric-

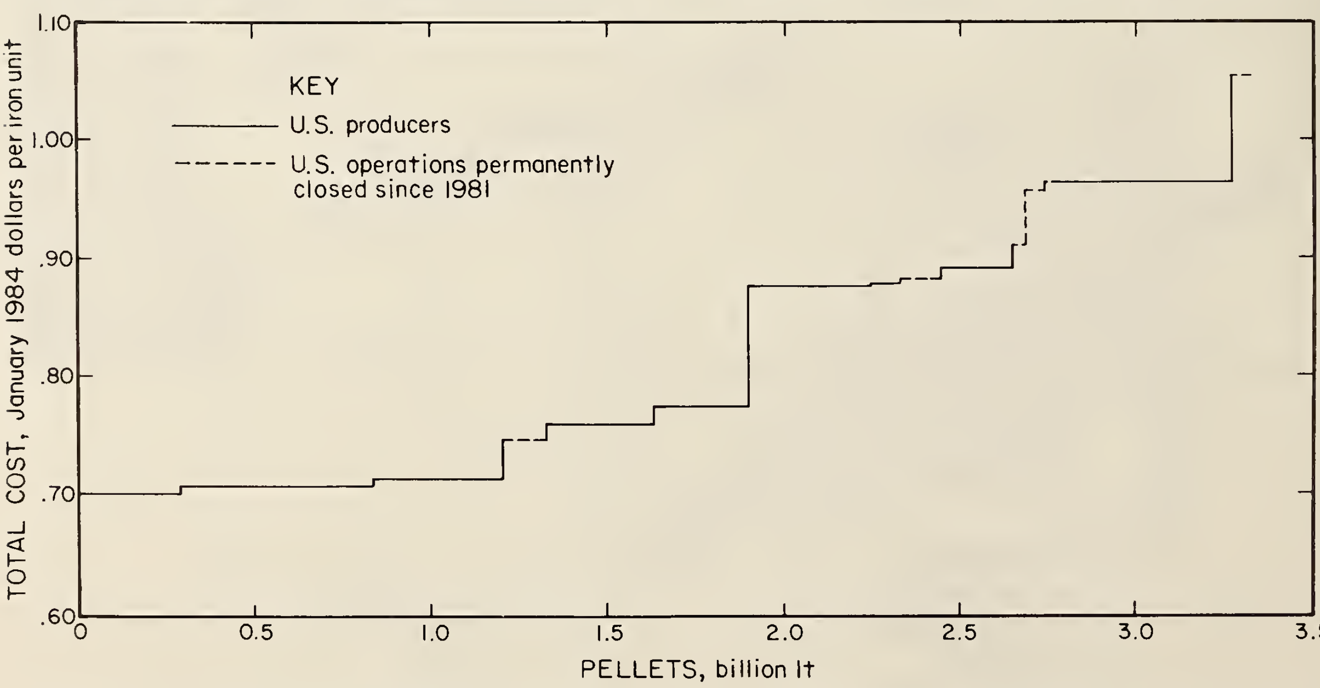

Figure 15.—Total potential pellet availability for selected domestic producers and operations permanently closed since 1981 at a 15-pct DCFROR.

tions be met, this development could lead to increased penetration of cheap foreign iron and steel into the domestic market, thus further lessening demand for U.S. iron ore, pig iron, and steel.

The recession affected the United States most severely in 1982. While U.S. resources of iron ore are theoretically sufficient to supply all domestic demand for the foreseeable future, it is unlikely that they will be developed beyond a self-sufficiency level of about 75 pct.

The current plight of the domestic steel industry has been blamed in part on cheaper foreign steel entering the United States; as a result, import quotas have been sought by the domestic industry to stem the flow of foreign steel into the country. However, other factors may have also played a role in the present economic conditions of the industry, including (1) higher domestic wage structure versus foreign competition, (2) the use of substitute materials such as plastics and aluminum, (3) a lag in modernization of facilities, (4) lower productivity levels of domestic plants versus foreign competition, and (5) long-range planning deficiencies. In view of the foregoing, further reductions in domestic iron ore production capacity are likely during the next few years.

Canada

The Canadian iron ore industry is characterized by a vertical integration of iron ore mines with parent mining and steel companies. A number of mines in Canada are predominantly controlled by U.S. mining and steel companies with minority ownership held by Canadian and European steel companies.

The large open-pit operation of Sidbec-Nonmines Inc. in Quebec-Labrador was permanently closed in December 1984, and the Griffith Mine at Red Lake, Ontario, was permanently closed in April 1986. These latest shutdowns reduce the number of iron ore producers remaining in Canada to six, which is less than half the number of 10 yr ago. The primary cause of the cutbacks in the Canadian iron ore industry in recent years has been attributed mainly to the decline in demand of iron ore. In spite of relatively high production costs, productivity in Canadian mines is high with utilization of the best available technology.

The vast Canadian resources of iron ore are capable of supporting Canadian and U.S. requirements for many years into the future. They are of special interest to the United States because of the present and continuing high degree of U.S. dependence upon Canadian iron ore. In 1984, Canadian shipments of iron ore to the United States totaled over 12.6 Mmt, of which 62 pct went to the Great Lakes area and the rest to coastal ports. Overall production in 1984 was 40.6 Mmt, of which 30.7 Mmt was exported. The other major export area is the European market, which accounted for 13.6 Mmt. Canada's production of iron ore in the past 5 yr has consisted mainly of pellets and sinter fines. These two products have accounted for 50.1 pct and 40.8 pct of total shipments of Canadian iron ore.

Reserves of iron ore in Canada are estimated at 25.3 billion lt containing 9.7 billion st Fe, with an average iron content of about 34 pct. Because of the low grades of the ore, most Canadian ore is beneficiated to a higher grade and is delivered to the steel mills either as oxide pellets made from concentrates or as a concentrate. In addition to reserves of 25.3 billion lt, there are approximately another 100 billion lt of prospective resources of iron ore in Canada. The greatest proportion of the economic reserves are in northeast and central Canada. Iron deposits in western Canada are generally higher grade and smaller, require underground mining, lack transportation, or pose beneficiation problems.

The four Canadian iron ore mines evaluated in this study have 6.2 billion lt of demonstrated iron ore resources at an average grade of 34.7 pct. From these mines nearly 933 MMlt of pellets are potentially available at total costs ranging from $0.86 to $1.03 per iron unit at a 15-pct DCFROR, f.o.b. port. An individual Canadian pellet availability curve is not shown to prevent disclosing proprietary information. However, these properties were included previously in the total pellet availability curve. Figure 16 shows the Canadian deposits evaluated in this study.

Most iron ore transportation in Canada involves relatively long rail shipments plus long distances on the St. Lawrence Seaway from mines to mills. Railways connect Canada's iron ore mines in the Labrador Trough to terminal ports on the Gulf of St. Lawrence and use unit trains owned by iron ore producing companies. Most shipments in Ontario are carried on the rail networks of the Canadian National and the Canadian Pacific. Freight rates are lowest on company-owned railways, which ship the largest annual tonnage of iron ore.

Large quantities of iron ore are carried on the Great Lakes-Gulf of St. Lawrence portion of the Seaway for shipment to both domestic and foreign markets. The most important Canadian loading ports are located at Pointe Noire, Port Cartier, and Sept-Iles on the Gulf of St. Lawrence. These three ports account for all of Canada's shipments to Europe and nearly all of the exports to the United States and Japan. Most of the iron ore shipments from these ports to the United States are shipped through the St. Lawrence Seaway, with the remainder being shipped to U.S. east coast and gulf coast ports.

Mexico

Production of iron ore, iron ore concentrates, and iron ore agglomerates amounted to 8.0 Mmt in 1983, with estimates of 8.4 Mmt in 1984. Although down from a high of 8.7 Mmt in 1981, this level of production in 1983 was achieved in spite of the economic recession in Mexico, which was characterized by a large foreign debt, several drastic devaluations of the peso, an inflation rate approaching 100 pct, severe unemployment, and a sharp reduction in new private sector investment. Mexico consumes all of its iron ore production internally and has, until recent years, been an importer of steel products to meet shortfalls in domestic production. In 1982 and 1983, however, reduced domestic demand for steel forced the steel companies to seek overseas markets for their products.

Mexico's resources of iron ore are modest in comparison to those of most producing countries, but so far they have been adequate to satisfy domestic requirements. The total resources are estimated at more than 600 Mmt at an average grade of 57 pct Fe. The Consejo de Recursos Minerales (CRM) has been involved in a program of exploration for iron ore and has identified 453 MMlt of iron ore reserves and 405 MMlt of additional resources at an average grade of 54 pct Fe. This represents less than 1 pct of total North American resources of iron ore. The five properties in Mexico evaluated for this study contain over 460 MMlt of demonstrated resources at an average grade of 46 pct Fe.

Iron deposits occur in many places in Mexico. About 35 individual deposits or closely spaced groups of deposits containing more than 1 Mmt each are known. One group is

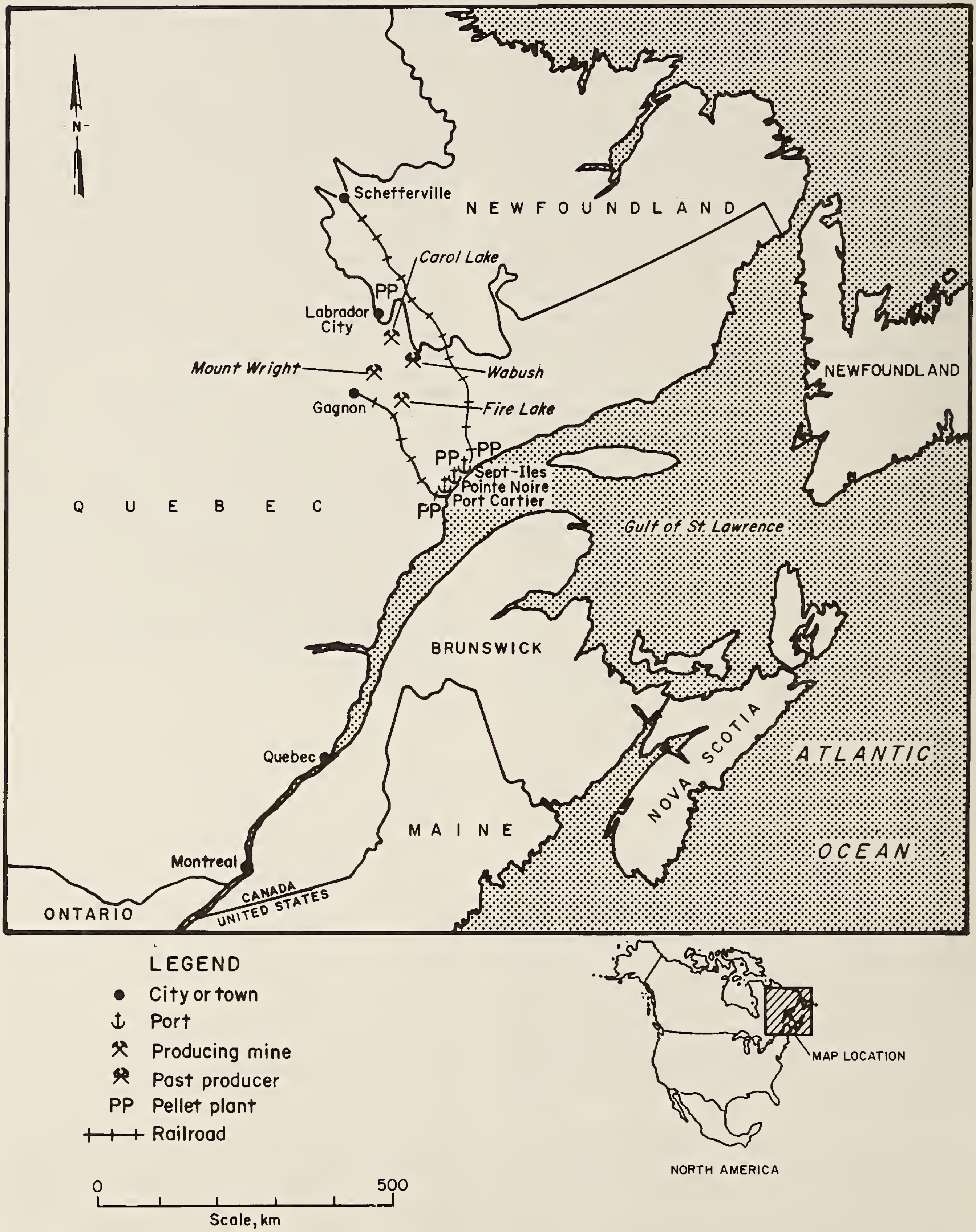

Figure 16.—Location map, Canadian deposits.

estimated to contain more than 130 Mmt. Most iron deposits in Mexico are massive deposits of the Kiruna and Magnitnaya types. Figure 17 shows the location of the Mexican deposits evaluated in this study.

Mexico has continued to expand its iron ore concentrating and pelletizing plants and by 1985 is expected to have a production capacity of about 17 Mmt/yr of iron ore products. Pellets will account for 14 Mmt/yr of this capacity. Ore requirements for meeting this new capacity will be provided in part by the development of mines in Coahuila, Colima, and Michoacan. Continued growth of the iron ore industry will exert further pressure to find and develop new resources to supplement the present known resources; however, future importing of iron ore is still a distinct possibility after a 10- to 15-yr period, when resources are projected to be inadequate.

The use of slurry pipelines to connect pelletizing and concentrating plants is rapidly becoming one of the major modes of iron ore transportation within the country. A 379-km pipeline with an annual capacity of 4.5 Mmt connects the La Perla and Las Hercules Mines to a new pellet plant at Monclova in Coahuila, northeast Mexico.

Of the four deposits evaluated in the study from which pellets are produced, 173 MMlt of pellets are potentially available within a total cost range of $0.49 to $0.97 per iron unit, f.o.b. port, at a 15-pct DCFROR. An individual availability curve for Mexico is omitted, but these deposits are included in the total pellet availability curve.

South America

The availability of the various iron ore products in South America was evaluated from a number of mines and deposits in Brazil, Venezuela, Chile, and Peru. Because of its importance in production and international trade of iron ore, Brazil is analyzed separately for sinter fines. The

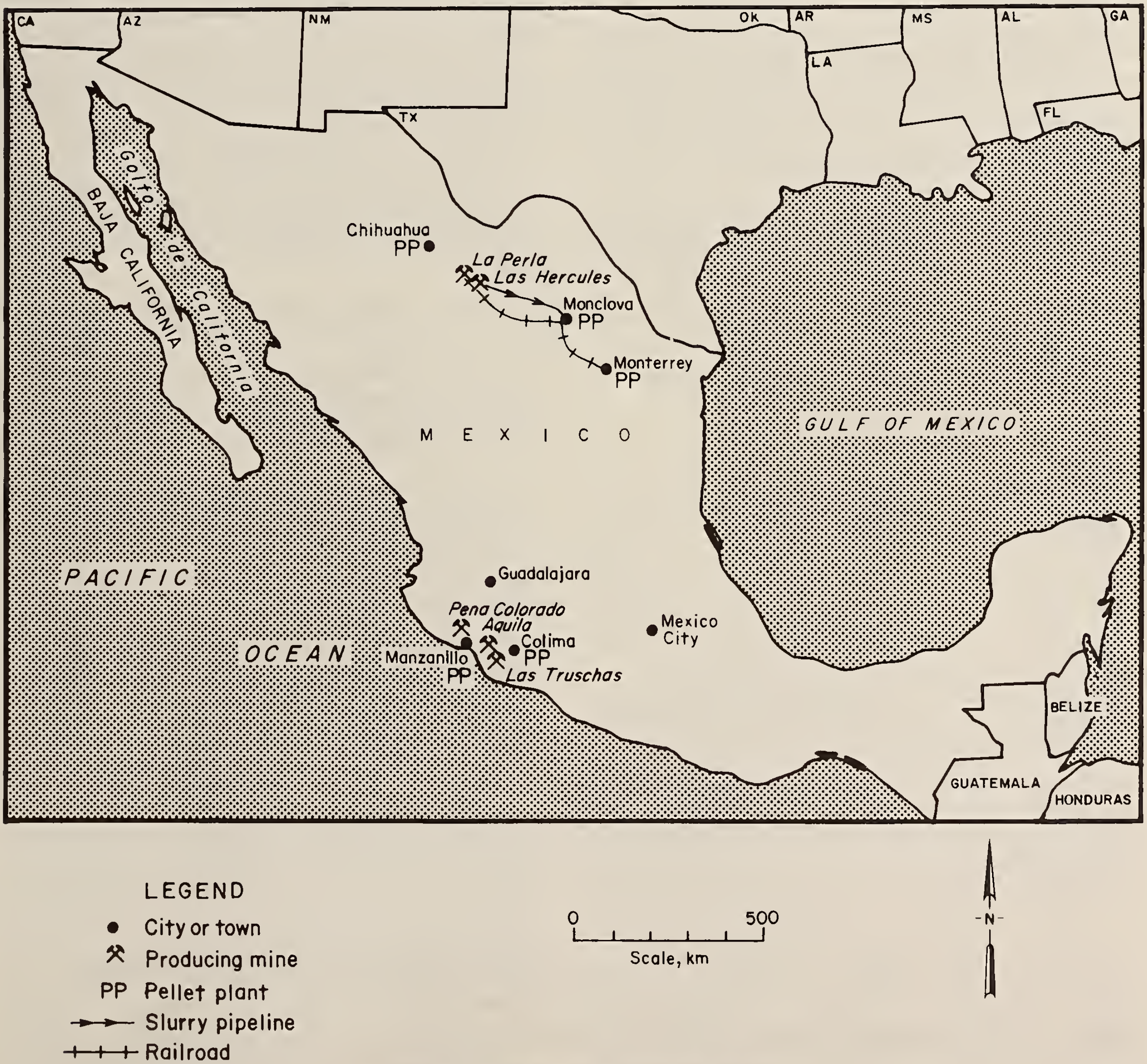

Figure 17.—Location map, Mexican deposits.

availability of the various iron ore products, as portrayed in the South American availability curves, consists of a combination of data from mines and deposits in Chile, Peru, and Venezuela.

The availability curves for Brazil and other South American countries, shown in figure 18, indicate that sinter fines are available at a much lower cost than that of any of the other iron ore products. As of 1984, there are potentially 1.7 billion lt (64 pct) of sinter fines available in Brazil from 13 producers. However, with the addition of the Carajas deposit production in 1985, this increased to approximately 2.7 billion lt of sinter fines available at a total cost less than $0.35 per iron unit, f.o.b. port. This accounts for nearly 15 pct of the analyzed 18.6 billion lt of potential sinter fines available in MEC's.

The 1984 market price for Brazilian sinter fines was approximately $0.26 per iron unit to Europe and $0.24 per iron unit to Japan, both f.o.b. port. Approximately 1.6 billion lt of sinter fines are potentially available from 12 producers for less than $0.24 per iron unit. Similarly, approximately 1.7 billion lt of sinter fines are potentially available at less than $0.26 per iron unit.

Five producers and five nonproducers in Chile, Peru, and Venezuela account for 7 pct of the total potential available sinter fines in MEC's. In these countries a total of 1.3 billion lt of sinter fines are potentially available at a total cost range of $0.17 to $0.54 per iron unit. Four producers account for 178 MMlt (13 pct) at less than $0.25 per iron unit, f.o.b. port, at a 15-pct DCFROR.

The Venezuelan sinter fines market price to Europe in 1984 was approximately $0.33 per iron unit, c&f. Assuming that the freight rate to Europe is similar to that for Brazil in the 50,000- to 65,000-DWT class, the shipping rate would be $0.09 to $0.10 per iron unit. Therefore, the f.o.b. price would be $0.24 per iron unit. Below this price 225 MMlt of sinter fines are potentially available from four properties, three of which are Venezuelan.

The market price for sinter fines from Chile and Peru to Japan in 1984 was around $0.21 per iron unit, f.o.b. port. At this price 225 MMlt of sinter fines are potentially available from four properties.

There is approximately twice the amount of sinter fines in Brazil as in Chile, Peru, and Venezuela. Also, comparison of the potential availability of sinter fines in Brazil with that in the other South American countries shows that there are 1,600 MMlt of sinter fines potentially available in Brazil compared with 220 MMlt in the other South American countries at less than $0.24 per iron unit, f.o.b. port, at a 15-pct DCFROR.

Figure 19 compares the availability of sinter fines from Africa, Australia, and Brazil. The curves show the potential available sinter fines up to 5.0 billion lt. The vast amount of potentially available Brazilian ore, 2.7 billion lt, at less than $0.35 per iron unit, f.o.b. port, further emphasizes Brazil's position as a major supplier of iron ore in international trade in the future. Australia has a total of 8.5 billion lt of sinter fines potentially available with 5.0 billion lt available at less than $0.38 per iron unit, f.o.b. port. Africa has approximately 3.9 billion lt of sinter fines potentially available; only 1.4 billion lt is available at less than $0.38 per iron unit, f.o.b. port.

Assuming an equal 1984 market price of $0.26 per iron unit for all three regions, there are potentially 1.7 billion lt, 2.8 billion lt, and 186 MMlt available, f.o.b. port, at a 15-pct DCFROR, for Brazil, Australia, and Africa, respectively.

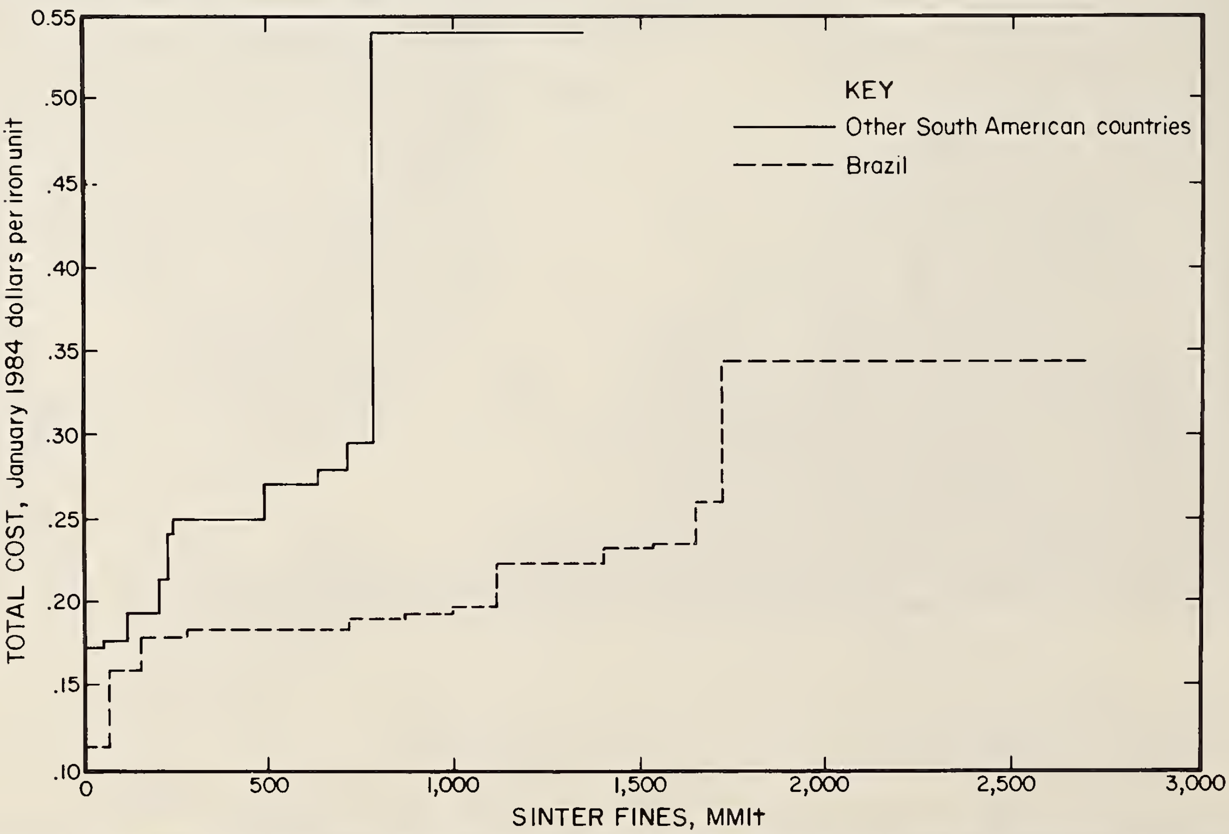

Figure 18.—Comparison of total potential sinter fines availability for Brazil and other South American countries at a 15-pct DCFROR.

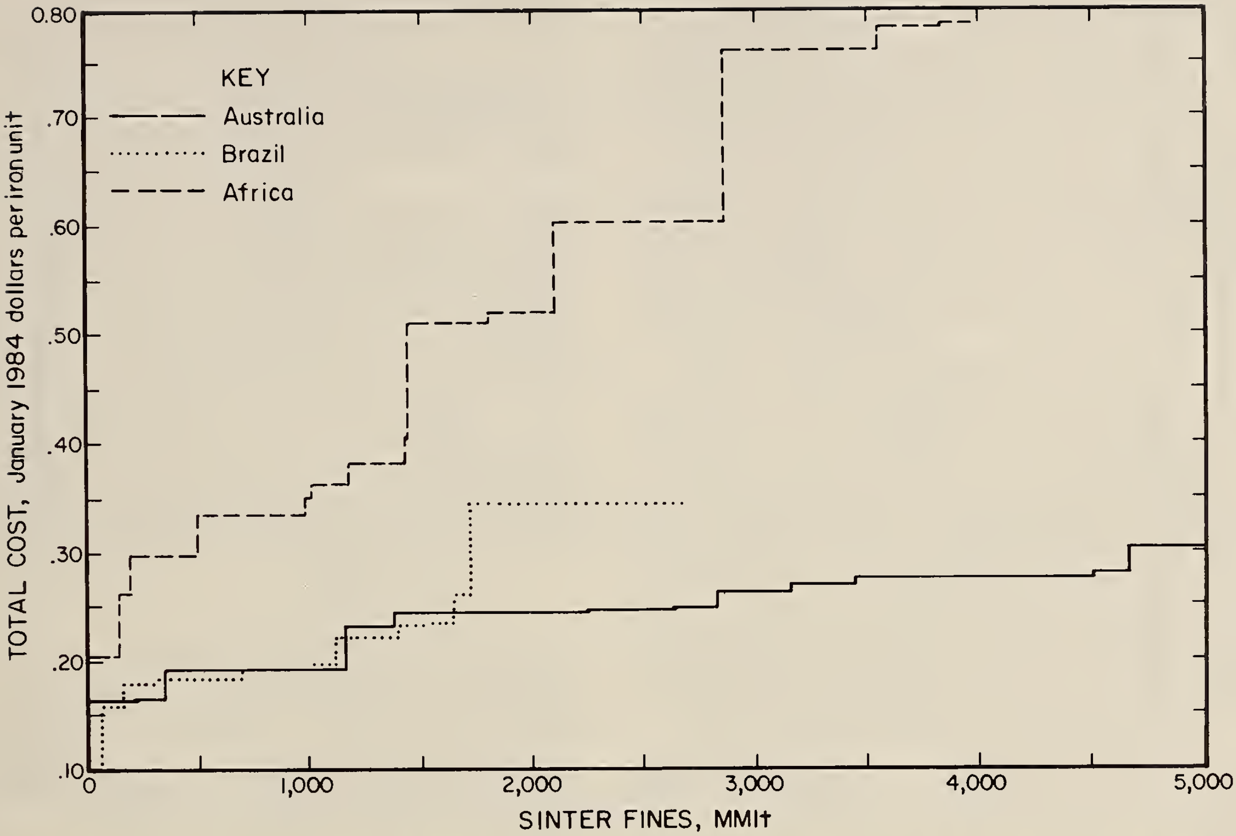

Figure 19.—Comparison of total potential sinter fines availability for Australia, Africa, and Brazil at a 15-pct DCFROR.

There is a close competitiveness between Brazilian and Australian sinter fines markets. As figure 19 shows, approximately 1.65 billion lt of both Brazilian and Australian sinter fines are potentially available at less than $0.24 per iron unit.

Brazil has the competitive advantage in the European market, while Australia has the competitive advantage in the Japanese market due to distances and shipping costs. This is illustrated in table 15 by comparing the 1984 market price and freight rates (per long ton) with the two major markets of Europe and Japan. In 1984 spot ocean shipping rates per long ton Fe for 64-pct-Fe ore from Brazil to Europe were $4.50 to $6.00 ($0.07 to $0.09 per iron unit) while Australian rates to Europe were $6.50 to $8.65 ($0.10 to $0.14 per iron unit). The rates per long ton Fe from Brazil to Japan were $7.00 to $9.00 ($0.11 to $0.14 per iron unit), compared with $5.00 to $6.00 ($0.08 to $0.09 per iron unit) from Australia to Japan. These are for bulk carriers in the 100,000- to 150,000-DWT class.

Potential availability of lump ore from Brazilian and other South American properties is compared in figure 20. Brazil has approximately 1.2 billion lt of lump ore available at a 15-pct DCFROR, f.o.b. port, which comprise 25 pct of the total evaluated MEC available resources of lump ore. From the 14 Brazilian mines and deposits evaluated, the 12 producing operations account for around 932 MMlt (78 pct) of the available tonnage at less than $0.30 per iron unit. Because this study is based on 1984 production, the Carajas Mine in Brazil is not included as a producer.

A total of 520 MMlt of lump ore are potentially available from eight Venezuelan and one Chilean iron ore mines, at a 15-pct DCFROR, f.o.b. port. Approximately 167 MMlt (32 pct) of lump ore are potentially available from four producers at less than $0.28 per iron unit. Again, it should be noted that the data of this study is 1984, at which time the Venezuelan San Isidro deposit was not in production.

Table 15.—Comparison of prices and freight rates for Brazilian and Australian sinter fines in European and Japanese markets

(1984 dollars per iron unit, 64 pct Fe)

Supplier	To Europe		To Japan	
	Price f.o.b.	Freight rate	Price f.o.b.	Freight rate
Brazil	0.26	0.07–0.09	0.24	0.11–0.14
Australia	[1].33	.10– .14	.26	.08– .09

[1]c&f rate.

Source: The TEX Report Ltd; Industrial Minerals.

The market price for lump ore in Brazil and Chile for the Japanese market was approximately $0.24 per iron unit, f.o.b. port. Therefore, given this market price, approximately 825 MMlt of lump ore are potentially available from eight producers and one nonproducer in Brazil at less than $0.24 per iron unit. In the other South American countries, approximately 280 MMlt of lump ore are potentially available at less than $0.24 per iron unit.

Figure 21 illustrates the potential total availability of pellets and pellet feed in South America at a 15-pct DCFROR, f.o.b. port. The pellet curve shows that 1.0 billion lt are potentially available from nine properties in Brazil, Chile, Peru, and Venezuela. Seven of these nine properties are producing and account for 955 MMlt of the potential available pellets. The 1984 market price for Brazilian

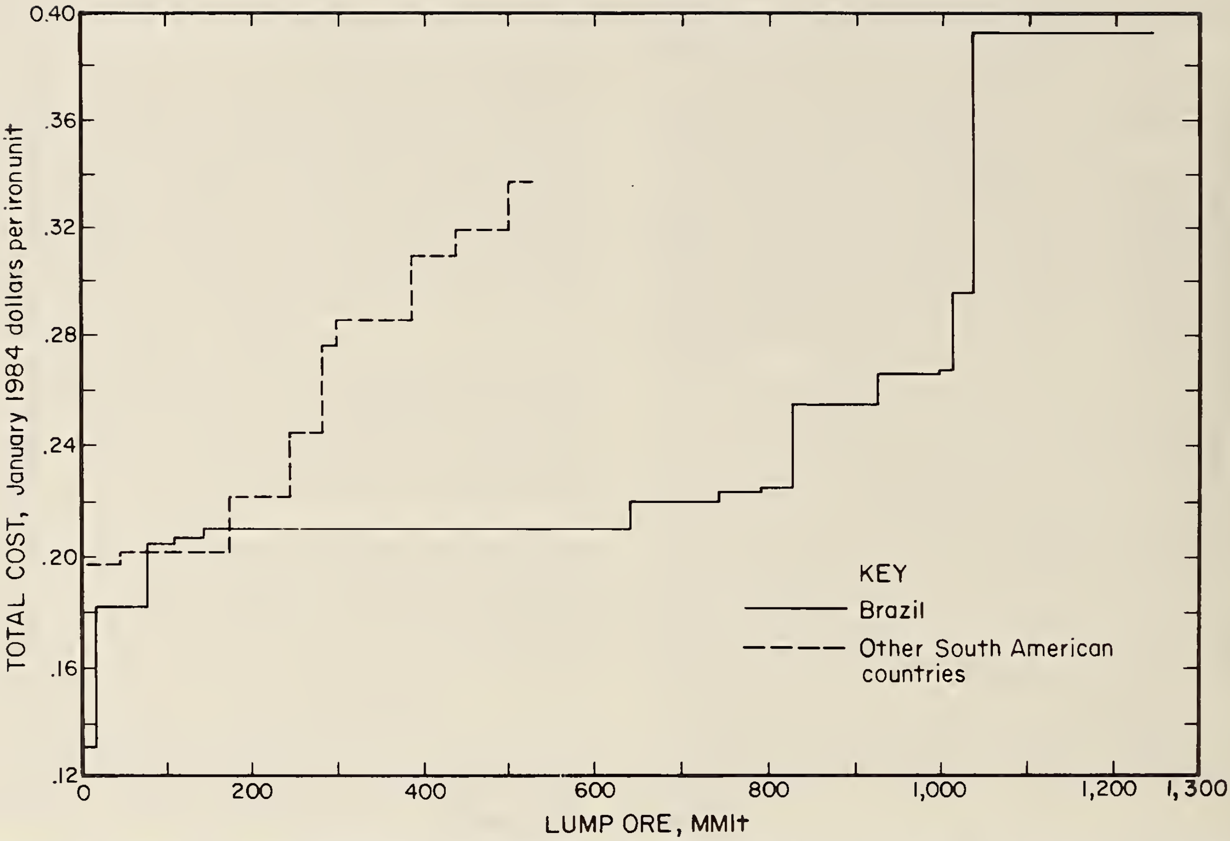

Figure 20.—Comparison of total potential lump ore availability for Brazil and other South American countries at a 15-pct DCFROR.

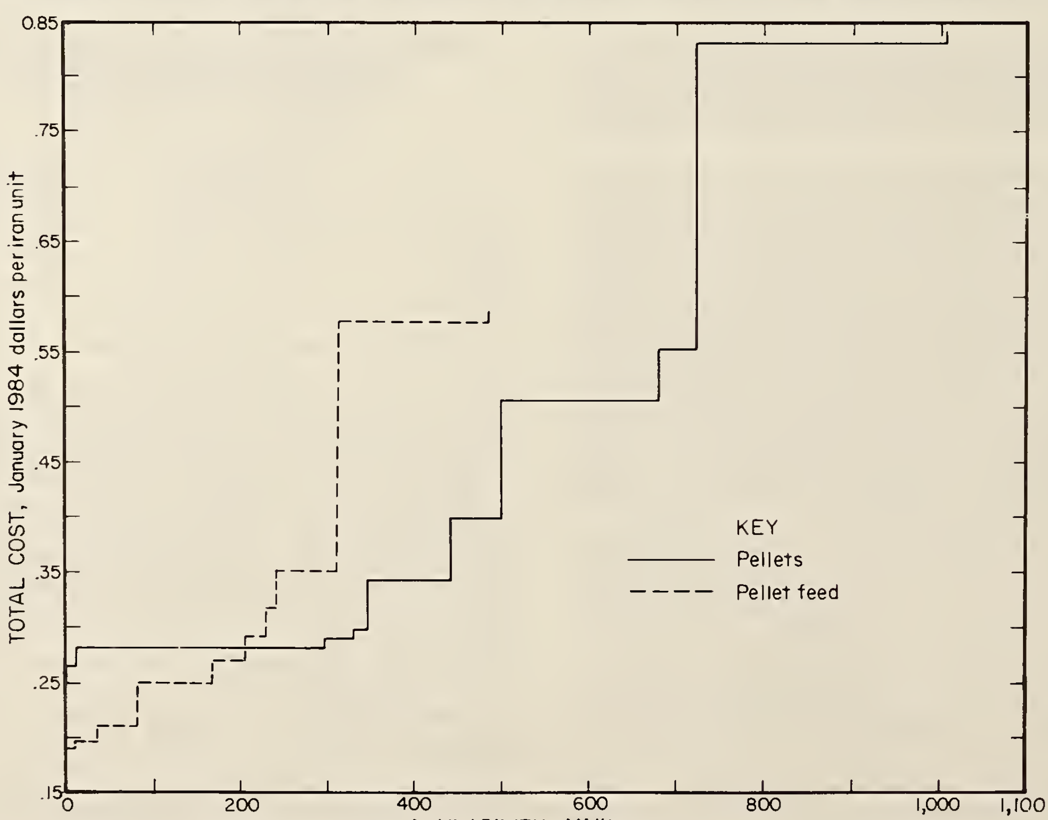

Figure 21.—Total potential pellet and pellet feed availability for South American countries at a 15-pct DCFROR.

pellets in the European market was $0.34 to $0.36 per iron unit, f.o.b. port. There are 442 MMlt of pellets potentially available at less than $0.38 per iron unit.

The pellet feed curve illustrates that approximately 480 MMlt are potentially available at a 15-pct DCFROR, f.o.b. port, from 11 properties in Brazil, Peru, and Venezuela. This constitutes approximately 59 pct of the 810 MMlt of potential pellet feed available in MEC's.

In this analysis five producers of pellet feed in South America accounted for 310 MMlt (65 pct) of the total potential available pellet feed in MEC's, with 23 pct available for less than a total cost of $0.25 per iron unit. The Carajas Mine in Brazil and the San Isidro Mine in Venezuela began production in 1985, increasing the potential available pellet feed. With this addition there will be approximately 410 MMlt (51 pct) of pellet feed available from producers, 42 pct at less than $0.27 per iron unit, f.o.b. port.

A 1984 market price for pellet feed was $0.28 per iron unit for pellet feed from Kudremukh, India, f.o.b. port. For comparison, approximately 208 MMlt of pellet feed from seven South American deposits are potentially available below this price, at a 15-pct DCFROR, f.o.b. port.

Brazil

Iron ore continues to be one of the most important minerals mined and exported from Brazil, making it a leading MEC exporter of iron ore. Until 1983, when gold surpassed iron ore as Brazil's number one source of mining revenue, iron ore led the country in the value of its mining or mineral production. It still accounts for over 90 pct of the value of its mineral exports. Along with Australia, Brazil is a leader in price negotiations, which have a significant impact on mines located in other parts of the world.

Brazilian resources are located primarily in two States—Minas Gerais in the southern, more developed part of the country, and Para, in the northern, more remote and less developed Amazon region. The southern resources are found mainly in the Quadrilatero Ferrifero (Iron Ore Quadrangle), while those in the north are mostly found near the municipality of Maraba in the Carajas Range. Brazilian iron ore resources are estimated to be 40 billion mt, of which 10 billion mt are contained iron in the measured category. Demonstrated resources of 5.3 billion lt of iron ore (at 63 pct Fe) were evaluated.

The mines of the Iron Ore Quadrangle have provided virtually all of Brazil's production; they have been more easily exploited owing to their location and existing infrastructure, while the Carajas deposits have been developed only recently. Figure 22 shows the location of deposits evaluated in Brazil for this study.

The Carajas resources have been termed the "discovery of the century." The region contains not only vast resources of iron ore but many other mineral deposits primarily located within a 60-km radius. The potential resources of iron ore are estimated at 18 billion mt, grading 66 pct Fe, of which 1.3 billion lt of demonstrated resources are evaluated. The State mining company, Cia. Vale do Rio Doce (CVRD), is the operator of the Carajas project. CVRD is one of the largest producers and exporters of iron ore in the world and, in 1981 accounted for 62.5 pct of the total Brazilian iron ore production of 98 Mmt. The Carajas project, at full capacity, is scheduled to produce 35 Mmt/yr of iron ore with the potential to eventually produce 50 Mmt/yr. Some 26.5 Mmt/yr have already been contracted for, primarily by Japan and European countries.

In the 1970's, Brazil's steel industry made rapid growth, and as of 1981 the domestic steel industry was consuming about 20 pct of its iron ore production. Brazil's steel industry has continued to grow to meet increasing domestic demand; Brazil plans to become a major world steel producer and currently is the largest in South America.

Brazil's major objective is to improve its balance of payments through, among other things, continued rapid expansion of exports. The Carajas project forms a major part of the Government's strategy for achieving this end. The project, through the establishment of a basic transport system, may have a major impact in the future development of other minerals as well, such as manganese, copper, bauxite, nickel, tin, and gold.

Major infrastructure requirements for the huge Carajas project have been undertaken by the Government. An 890-km railroad from the iron ore deposits to the port at Sao Luis on the Atlantic Ocean is nearing completion. The railroad has been designed to transport 35 Mmt/yr. The shiploading port will handle vessels up to 280,000 DWT and will be equipped to load ships at the rate of 16,000 mt/h. The combined cost of the railroad and port facilities amounts to about 60 pct of the total estimated project cost of $4.9 billion. The project is being financed through resources of CVRD and the Brazilian Government and loan arrangements with various financial institutions including the World Bank and European, Japanese, and U.S. banks.

The iron ore from the Carajas deposit is considered some of the world's best in terms of iron content, low silica, and metallurgical properties. It is predominantly high-grade sinter feed, which is in demand as an export product. Because of its high natural iron content, Carajas ore requires no beneficiation other than crushing and screening to produce sinter feed and pellet size lump ore.

The second largest exporter of iron ore in Brazil is Mineracoes Brasilieras Reunidas S.A. (MBR), a private sector company. MBR exported 10.6 Mmt and shipped 0.9 Mmt for domestic consumption in 1981 and planned to increase its production capacity to 25 Mmt/yr by 1986.

Samarco Mineracao S.A. (SAMARCO) is a Brazilian corporation jointly owned by S.A. Mineracao da Trindade (SAMITRI) (51 pct) and Utah International Inc. (49 pct). SAMARCO owns and operates an open-pit mine capable of producing 10 Mmt/yr of iron ore. The mine, one of Brazil's largest, operates the world's biggest iron ore slurry pipeline.

Four companies accounted for about 90 pct of all Brazilian shipments of iron ore, concentrates, and pellets in 1983, totaling 98.1 MMlt. The four major companies are CVRD, Ferteco Mineracao S.A., MBR, and SAMITRI.

Venezuela

Venezuela has about 2 billion lt of crude iron ore reserves, most of which are situated in the Imataca belt. The deposits are of the Lake Superior type and follow the valley of the Orinoco River. The eight mines and deposits evaluated in this study have approximately 1.4 billion lt of demonstrated resources at an average grade of 63 pct Fe. Figure 23 shows the locations of deposits evaluated in Venezuela for this study.

Venezuela ranks second to Brazil in South America as a major producer and exporter of iron ore. In 1960, Venezuela was the major source of iron ore imported into the United States, surpassing Canada. It has since lost this position back to Canada and in the period 1979-83 furnished about 15 pct of all U.S. imports versus Canada's 67 pct.

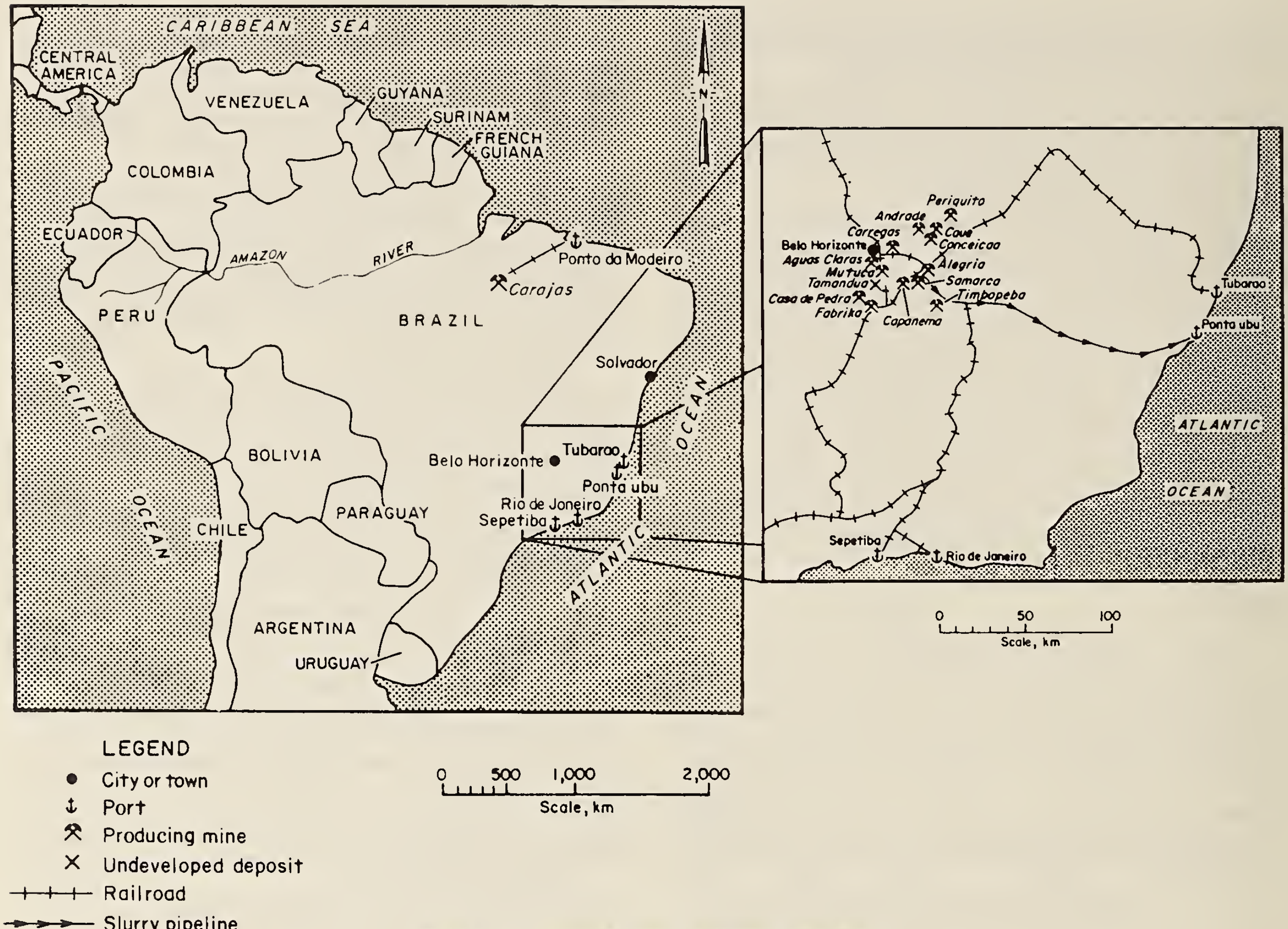

Figure 22.—Location map, Brazilian deposits.

Specifically, exports to the United States decreased to 1.4 Mmt in 1983, the lowest in over 30 yr. Production of iron ore overall has shown a steady decline in the past 10 yr, from 26 Mmt in 1974 to 9.6 Mmt in 1983.

The iron ore industry is 100 pct nationalized and is under the control of the CVG Ferrominera Orinoco C.A. (FERROMINERA), which is part of Corporacion Venezolana de Guayana (CVG), the state-controlled development corporation for the Guayana Province, in which most of the iron ore is located.

The iron ore mines of Venezuela were developed as captive mines almost exclusively by two U.S. companies—United States Steel Corp. and Bethlehem Steel Corp. Prior to nationalization of the mines on January 1, 1975, most of the Venezuelan exports of iron ores were to these two companies on a captive basis, with 40 pct sold to Europe. It is unlikely that future exports of iron ore to the United States will be as significant as in the past, owing to Venezuela's increased domestic demand and reduced U.S. consumption.

The long-range strategy of CVG is to increase the use of its own production of iron ore within the country for production of direct-reduced iron and steel. In 1982, total exports of iron ore to all consumers was less than 7 Mmt while domestic consumption increased to 3.7 Mmt. The principal Venezuelan consumer of iron ore is Siderurgica del Orinoco C.A. (Sidor), the steelmaking subsidiary of CVG, at the Matanzas iron and steel plant, near Ciudad Guayana. The Matanzas plant, with a crude steel capacity of 4.8 Mmt/yr, is the world's largest integrated steelworks based mainly on direct reduction technology.

FERROMINERA is now developing the high-grade San Isidro deposits, which contain nearly 390 Mmt of iron ore at an average grade of 64 pct Fe. This project is scheduled eventually to have a capacity of 5 Mmt/yr and will replace some of the production from the depleting Cerro Bolivar deposit. This will give Venezuela a potential capacity of about 24 Mmt/yr.

Two main ports are used for shipping iron ore products: Puerto Ordaz and Palua. A major expansion of iron ore stockpiling, screening, shiploading, and railroading facilities at Puerto Ordaz has been completed for CVG FERROMINERA. Blending capacity has been doubled, and since increasing quantities of ore will ultimately be retained for domestic steelmaking, a high-speed railcar loading facility, capable of loading ore at the rate of 15,000 mt/h, has been constructed for shipment of ore to the Matanzas steel plant.

Exports of iron ore from Venezuela are mostly sold under c&f terms as opposed to f.o.b. terms, in which approximately 85 pct of all iron ore on the international market is sold. The size of vessels and difficult navigational conditions are handicaps to Venezuelan exporters owing to limitations imposed by the Orinoco River, where maximum water depth varies from 9 to 13 m according to the season.

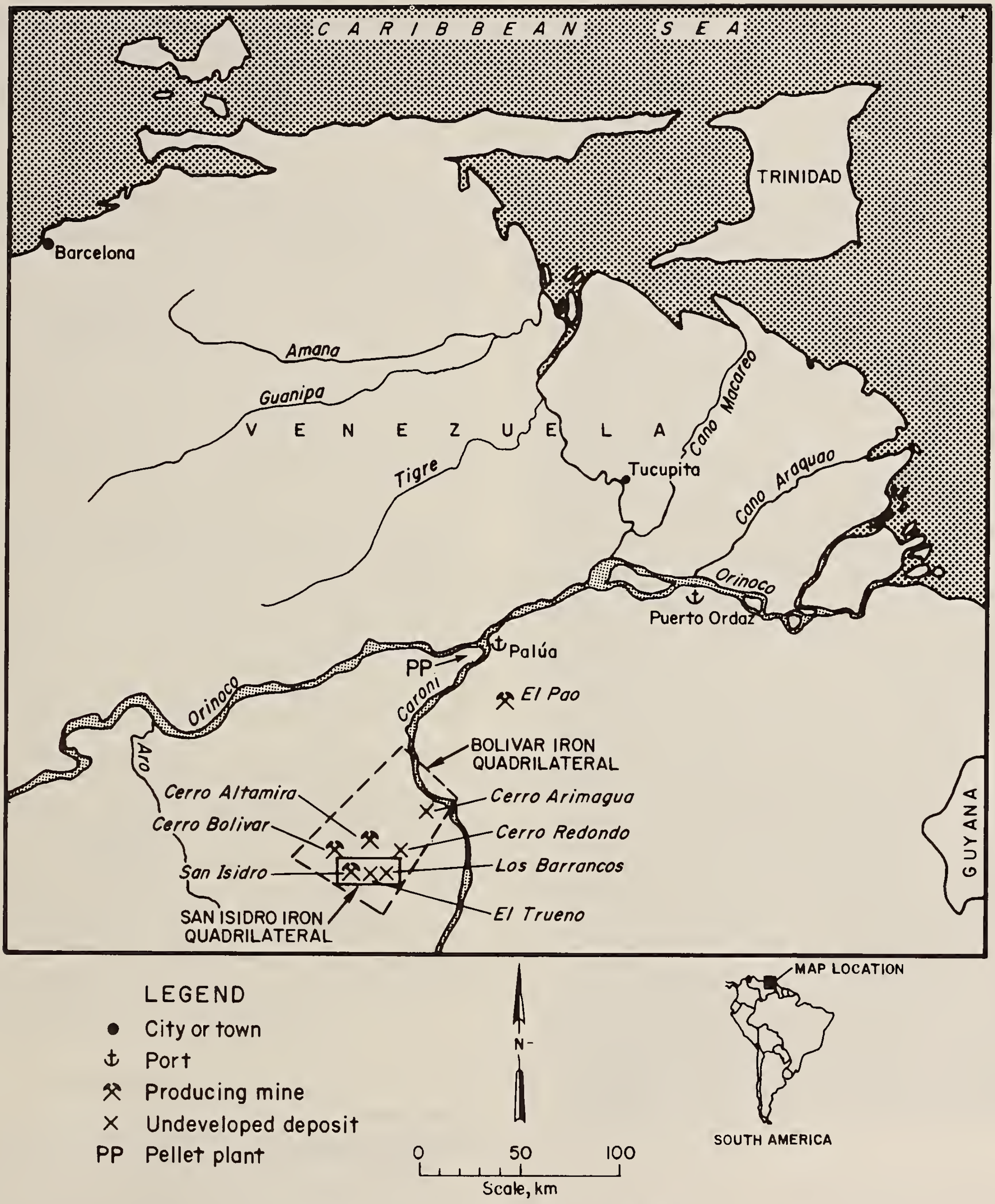

Figure 23.—Location map, Venezuelan deposits.

Chile

In Chile, more than 100 deposits of iron ore are known, and resources are estimated at 900 Mmt with 220 Mmt of contained iron. Chile's iron ore lies mainly in a fault zone 600 km long and 25 to 30 km wide, paralleling the Andes Mountains. The ore is mostly massive magnetite altered to martite. Demonstrated Chilean resources of over 140 MMlt at 54 pct Fe were evaluated. Two deposits comprise this resource, the El Romeral and the El Algarrobo. Figure 24 shows the locations of the evaluated Chilean and Peruvian deposits.

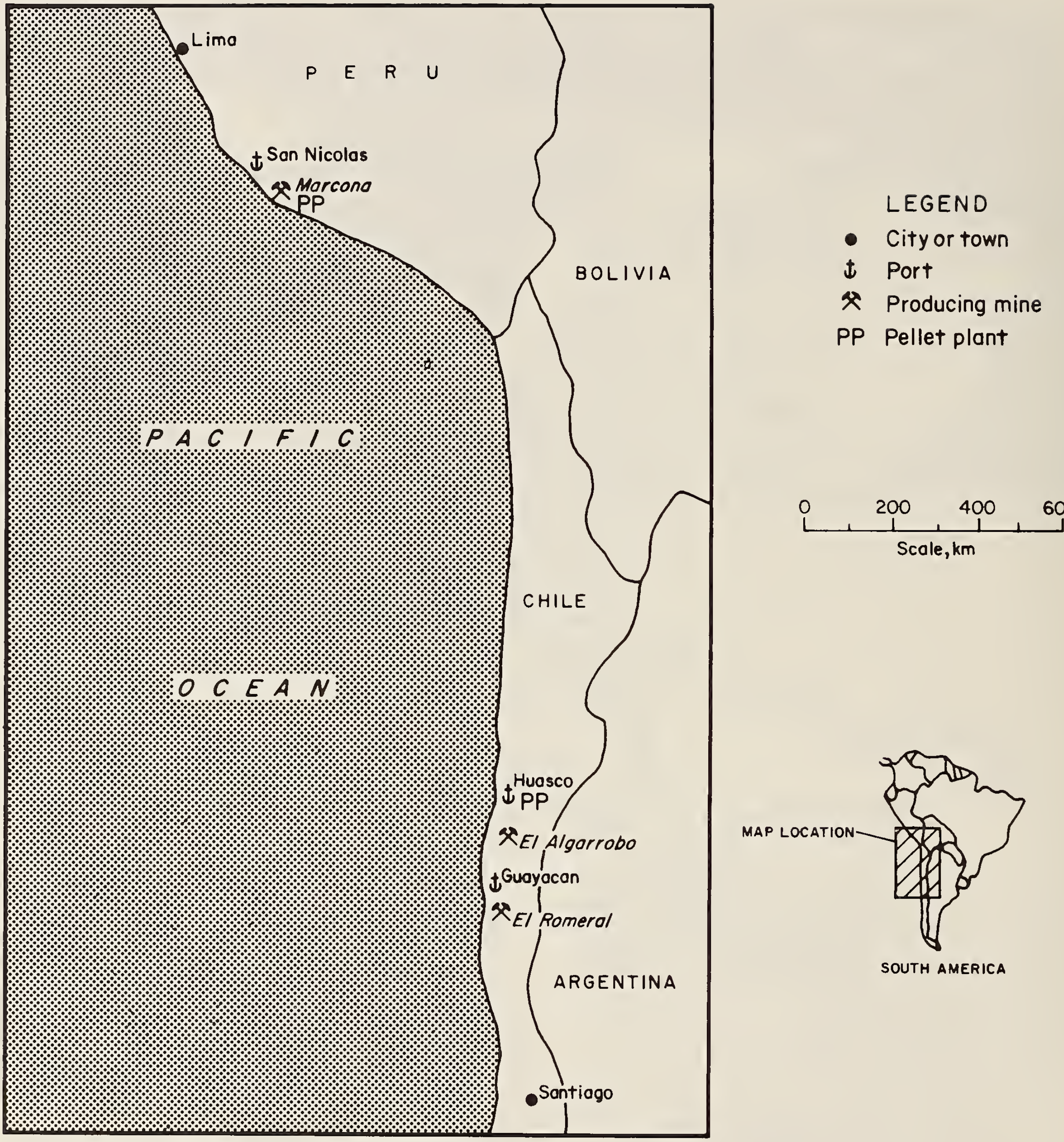

Figure 24.—Location map, Chilean and Peruvian deposits.

Iron ore output of Chilean mines has been steadily declining for the past 10 yr. Total production of iron ore, iron ore concentrate, and iron ore agglomerates dropped from 10.1 Mmt in 1974 to about 5 Mmt in 1983. International and domestic recessions have had severe repercussions on Chile's main producing company, Cia. de Acero del Pacifico S.A. (CAP) (Pacific Steel Co.). Reduced sales to Japan, Chile's major customer for over 20 yr, have forced the company to offer three of its properties for sale. The outlook for the Chilean iron ore industry is one of diminishing capacity and exports owing to quality problems, low demand, and distance from markets. Productivity has decreased, partly as a result of nationalization, and it is unlikely that present capacity can even be maintained. The 1984 production of iron by CAP was 3.4 Mmt of El Algarrobo pellets and 2.2 Mmt of lump ore and fines from El Romeral. Total shipments in Chile were 6.3 Mmt, consisting of 5.2 Mmt for export and 1.1 Mmt for consumption at Huachipato.

Labor unrest has infiltrated the iron ore industry, primarily as a result of a synergistic effect from very militant copper mining unions. The Chilean Government has

stabilized the situation recently, in recognizing the need for a stable mining industry. The current level of technology is limited, and it is unlikely that capital will be made available to modernize the industry, under its present depressed condition.

Peru

Large resources of high-grade iron ore are present in Peru, specifically the deposits of Marcona and Acari. The only iron ore mine operating is the Marcona Mine, about 530 km south of Lima. The Empresa Minera del Hierro del Peru (Hierro Peru) owns and manages the Marcona Mine, which consists of numerous opencast pits. The ore, contained in several ore bodies, occurs as massive magnetite as well as hematite-martite. The proven reserves are estimated at 600 Mmt containing 46 pct Fe. Evaluated in this study are over 1.4 billion lt of demonstrated resources at 53 pct Fe at the Marcona Mine. Other minerals present in the ore are sulfides of cobalt, copper, and nickel. The company plans to recover copper and cobalt from the San Nicolas tailings, with the pyrite concentrate containing 0.25 pct Cu and 0.60 pct Co.

The product distribution of Peruvian iron ore is mostly in the form of high-grade sinter feed and pellets. The production capacity of the Marcona facilities is rated at 7.5 Mmt/yr. In 1984, Marcona produced 3.87 Mmt of iron concentrates. Production of iron ore in Peru has declined steadily, falling from 9.4 Mmt in 1973 to an estimated 4.4 Mmt in 1983. The tonnage is produced mainly for export to the Republic of Korea, Japan, and Europe. Domestic consumption has been modest, with approximately 480,000 mt of mostly pellets consumed in 1983 by the Chimbote iron and steel plant.

Hierro Peru is discussing trade agreements with potential customers in Europe in an attempt to increase its exports of iron ore. It is also considering capital expenditures to reduce the sulfur and alkali content of its iron concentrates to make its products compatible with increasingly stringent environmental standards of many of the importing countries and to make its ore more competitive with other low-sulfur ores. An expansion of port facilities at San Nicolas to accommodate vessels up to 250,000 DWT, instead of the 160,000 DWT now being used, is also under study. Another possibility being explored, to enhance its iron ore industry, is the trading of iron ore with Yugoslavia in exchange for locomotives and railroad cars.

Australia and New Zealand

Australia has a vast reserve base of iron ore, estimated at 33 billion lt containing 20.2 billion st Fe. Australia produced an average of 89.2 MMlt/yr of iron ore products in the 10-yr period of 1974-83. Over 11 billion lt of demonstrated resources of iron ore at an average grade of 60 pct Fe were evaluated in this study.

The main customer has been Japan, and the industry's installed export capacity of about 100 MMlt was primarily built to meet Japanese contract requirements. Other markets are also becoming increasingly important for Australian iron ore as larger orders are being placed from Taiwan, the Republic of Korea, and China. Shipments to Taiwan and the Republic of Korea were significantly higher in 1982, as steel output in those countries continued to expand, in contrast to the world trend. Exports of iron ore to China appear to offer the greatest prospect of long-term growth in the Australian industry. A $200 million joint venture mine is being considered in the Pilbara district to ultimately produce 10 Mmt/yr for the Chinese. The export trade is based on the iron ore reserves of the Pilbara district of northwest Western Australia. The major ports exporting ore are Dampier, Port Hedland, and Port Walcott. Evaluated deposits within the Pilbara district in the study are shown in figure 25. In this area, five major companies produce about 90 pct of Australia's total iron ore output: Hamersley Iron Pty Ltd., Mount Newman Iron Ore Pty Ltd., Cliffs Western Australia Mining Co., Robe River Iron Association, Goldsworthy Mining Ltd., and Broken Hill Pty Ltd.

High-grade lump ore is a major product of Australian mines, accounting for over 50 pct of the production from the producing mines in 1982. Australia continues to be a dominant producer and exporter of iron ore on the world scene despite being plagued by a history of strikes and bad industrial relations from the inception of the industry in the country. However, once the mines are operating, labor productivity is quite high, with the large-scale open pit mines utilizing the best available technology. High wages and high turnover rates among the labor force are common to the industry.

Pellet plant operations have been suspended by the Hamersley and Robe River companies due to high fuel costs. The possibility of restarting the Dampier pellet plant has been ruled out due to the poor potential for long-term markets. The plant has a capacity of 3.0 Mmt/yr, and the Cliffs-Robe River plant has a capacity of 5.0 Mmt/yr. The Savage River and Whyalla pellet plants continue to operate. The locations of the Middleback Range and Savage River deposits are shown in figure 26.

Australia is one of the lowest cost producers of iron ore in the world today, making its operations very competitive on the world market. This is attributable to several factors—large, high-grade deposits; high production; highly automated nature of the industry in both mining and shipping; and short distances to Japanese markets.

Sinter fines are potentially available from 19 of the 20 mines and deposits evaluated in Australia. Figure 19 shows 5.0 billion lt of a total of 8.5 billion lt of sinter fines available, accounting for nearly 46 pct of the total available sinter fines in MEC's. This tonnage is available within a total cost range of $0.16 to $0.38 per iron unit at a 15-pct DCFROR, f.o.b. port.

Of the five producers, four have total costs less than $0.24 per iron unit and contain nearly 1.4 billion lt (16 pct) of the potentially available sinter fines in Australia. The 14 nonproducers account for a total of 7.1 billion lt (84 pct) of sinter fines potentially available within a total cost range of $0.24 to $0.38 per iron unit at a 15-pct DCFROR, f.o.b. port.

Australian prices for sinter fines in Europe in 1984 were $0.33 per iron unit, c&f. Spot freight rates in 1984 from Australia to Western Europe were $6.50/mt to $8.75/mt, or $0.10 and $0.14 per iron unit, assuming 64 pct iron. At a market price of $0.33 per iron unit and a $0.10 per iron unit freight rate, an f.o.b. price would be approximately $0.23 per iron unit. At this market price there are 1.4 billion lt of sinter fines potentially available.

Approximately 2.6 billion lt of sinter fines are potentially available at less than the 1984 price for Australian sinter fines to Japan of around $0.26 per Fe unit, f.o.b. port. Freight rates ranged from $5.00/lt to $6.00/lt in 1984 from Australia to Japan, which is approximately equivalent to $0.08 to $0.09 per iron unit at 64 pct Fe. Therefore, it is

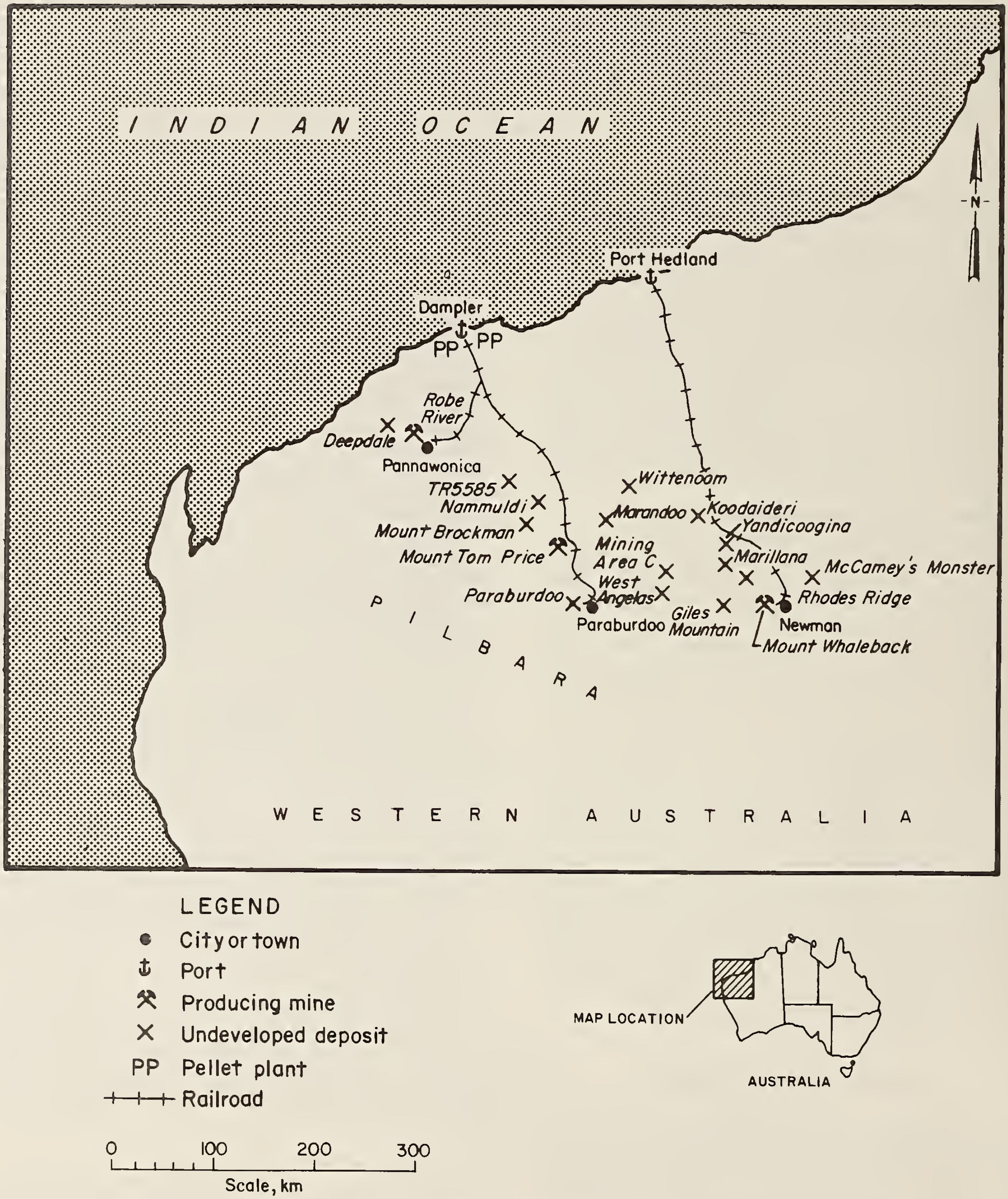

Figure 25.—Location map, Western Australian deposits.

estimated that the total cost could be as high as $0.35 per iron unit.

Approximately 1.4 billion lt of lump ore are potentially available from six mines within a total cost range of $0.18 to $0.43 at a 15-pct DCFROR, f.o.b. port. This availability is not shown graphically because of the small number of properties and to ensure confidentiality. Australian resources account for 29 pct of the total lump ore available in MEC's. Three producers account for 82 pct of this potentially available ore at less than $0.27 per iron unit.

Australian iron ore prices for lump ore in 1984 were approximately $0.36 per iron unit, c&f, to Europe. As discussed earlier with sinter fines, freight rates to Europe in 1984 ranged between $0.10 and $0.14 per iron unit.

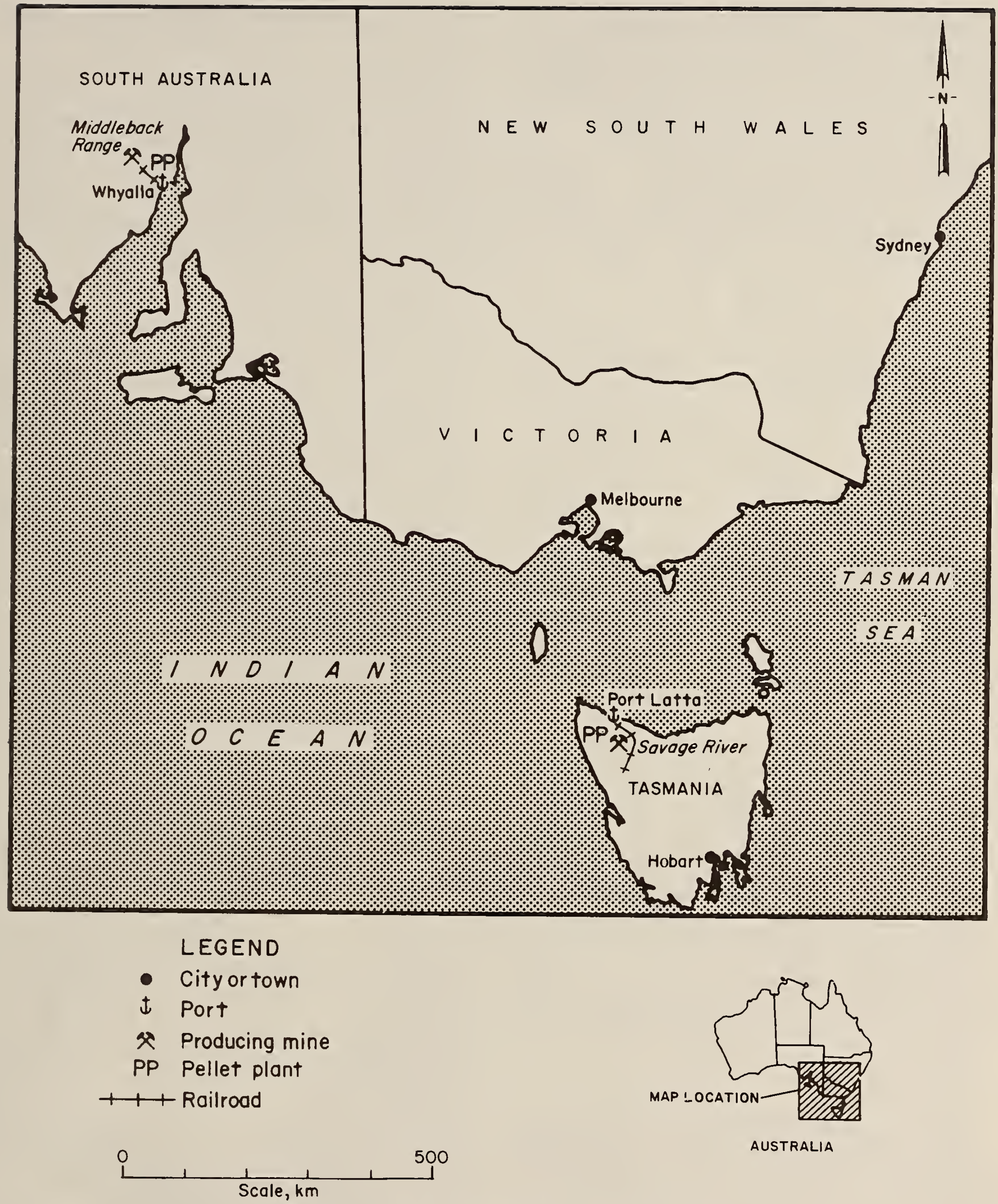

Figure 26.—Location map, Southern Australian deposits.

Therefore, it is estimated that an f.o.b. price would be approximately $0.26 per iron unit. Approximately 1.1 billion lt of lump ore are potentially available at a total cost of $0.40 per iron unit, f.o.b. port.

Prices to Japan were approximately $0.31 per iron unit, f.o.b. port. At a total cost of $0.31 per iron unit approximately 1.3 billion lt of lump ore are available, f.o.b. port. At a freight rate of $0.08 to $0.09 per iron unit (64 pct Fe) the total cost to the buyer could be as high as $0.40 per iron unit.

The North Island of New Zealand contains beach sand deposits of titanomagnetite derived from volcanic rock. It

is estimated that more than 1.0 billion mt of titanomagnetite occur in seven deposits along the west coast of North Island. The location of the Waipipi deposit is shown in figure 27. Total exports of ore from New Zealand to Japan range from 2 to 3 Mmt/yr. Waipipi Ironsands Ltd. exports nearly 1.0 Mmt/yr to Japan, partly because of the demand for TiO_2 in newly lined blast furnaces. Additions of 5 to 7 kg titaniferous ore per metric ton of iron to the blast furnaces aids oxygen removal and extends the life of the blast furnace refractory linings. With several long-term contracts with Japan and its own steel industry, the iron ore industry of New Zealand continues to survive despite its small scale and geographic location.

Europe

The availability of iron ore in Europe was evaluated from deposit data from four countries—Sweden, Norway, Spain, and Portugal. Other European MEC's as well as the U.S.S.R. and other CPEC's were excluded from the study. The criterion for the selection of the deposits was whether an individual property might have an impact on actual availability and have the potential to produce for international trade. Therefore, countries such as France and the Federal Republic of Germany, which use most of their iron ore internally, were not included. Because its ore is low grade and beneficiation processes are designed accordingly, France imports nearly half of its ore from other sources.

The European desposits evaluated contain an estimated 2.5 billion lt of demonstrated resources containing 46 pct Fe. While an availability curve was not constructed for Europe, the potential pellet availability for four mines ranges between 242 and 490 MMlt at a total cost range of $0.55 and $1.23 per iron unit, f.o.b. port, at a 15-pct DCFROR.

The 1984 market price for Swedish and Norwegian pellets in Europe was approximately $0.38 per iron unit, f.o.b. port. All the European properties evaluated for pellets in this study have higher total costs per iron unit than the market price of $0.38 per iron unit. This is an example of how Government support through ownership and subsidies can keep these producers in the marketplace.

Four evaluated iron ore properties in two European countries account for 11 pct of the total 4.9 billion lt of lump ore potentially available in MEC's. This availability is not illustrated graphically because of the small number of properties and to ensure confidentiality. There are approximately 475 MMlt of lump ore potentially available from producing mines within a total cost range of $0.19 to $0.59 per iron unit, f.o.b. port.

Sweden and Norway

Sweden was one of the first countries to develop its iron ore resources for the export market. Demonstrated resources of 2.0 billion lt were evaluated from three properties in Sweden. Sweden's reserve base is nearly 4.6 billion lt of crude ore.

The iron ore deposits of Northern Sweden, north of the Arctic Circle, contain some of the world's most important sources of high-grade iron ore. The ore bodies of the Kiruna district—Kirunavaara, Luossavaara, Malmberget, and Svappavaara—account for over 90 pct of Swedish exports and approximately 60 pct of domestic deliveries. The other major source of Swedish iron ore is the Grangesberg area in central Sweden, with the principal mines about 150 km west of Stockholm. Deposit locations of properties evaluated in Sweden and Norway are shown in figure 28. The ore types found in Sweden are banded iron quartzites, apatite iron ores, calcareous high-manganese ores, skarn ores, and titanomagnetites.

Sweden's iron ore production is dominated by Luossavaara-Kirunavaara AB (LKAB), a Government-owned company and one of the world's five largest exporting companies. LKAB produces 80 pct of Sweden's iron ore from three mines north of the Arctic Circle. Two of the mines, Kiruna and Malmberget, are underground sublevel caving operations. The third, Svappavaara, an open pit mine, has not been in operation for some time. Over 90 pct of Swedish iron ore comes from underground mines, whereas in the rest of the world open pit mining accounts for 85 pct of all production.

Ore from the mines of northern Sweden is transported by rail to the ports of Narvik in Norway and Lulea in Sweden. The iron ore railway from Lulea to Narvik, owned and operated by the Swedish and Norwegian State Railways, covers 435 km in Sweden and 39 km in Norway.

Declining export demand for Swedish iron ore resulted in 1982 shipments approaching the 1949 level. Sweden exported 12.7 Mmt in 1982, and domestic consumption was 2.4 Mmt. Production from Swedish mines has steadily declined from 36.4 Mmt in 1974 to 15.9 Mmt in 1982. Mines in Sweden were shut down for 10 to 15 weeks, and the new pelletizing plant at Kiruna, with a 3-Mmt/yr capacity, was utilized at only 40 pct of capacity during 1982. Other pellet plants at Malmberget and Svappavaara bring LKAB's total pellet plant capacity of 9.0 Mmt.

The total shipping capacity of the ports that LKAB utilizes is 39 Mmt/yr—30 Mmt/yr at Narvik and 9 Mmt/yr at Lulea. The port of Narvik can accommodate two 100,000-DWT vessels at the older quays and a 350,000-DWT vessel at the new quay. The port is ice-free year round, whereas the port of Lulea is closed by ice for 5 months. Lulea has an ore storage capacity of 5 MMlt.

With the long-range trend toward a rising world production of iron ore, mostly from large open pits, underground Swedish mines face stiff competition. Despite having large resources of high-grade iron ore, Sweden's future in the world commerce of iron ore remains tenuous. Several reasons exist, including possibly higher production costs because of the high proportion of underground mines as opposed to open pits, higher labor rates, and social costs. Another major competitive problem, which will not disappear even if the demand for iron ore increases significantly, is the high phosphorus content of much of Sweden's magnetite ore reserves. The ores of the Kiruna district average between 1 and 2 pct phosphorus (P) and 60 to 68 pct Fe. The change in steelmaking technology has resulted in a move away from these ores, and only six steel plants in Europe now accept such material. Because the high phosphorus content in the ore increases beneficiation costs, a smaller amount of this type of ore is being produced each year. In the last 10 to 15 yr, however, progress has been made in recovering the waste P_2O_5 and developing this into a fertilizer industry.

On the positive side, Sweden has a very stable labor force and has been a world leader in the development of new equipment and technological innovations in mining methods and ore processing. These factors, including inexpensive ocean freight costs, along with ample resources, may help Sweden to retain some of its share of the iron ore market.

Reserves and resources of iron ore of the Lake Superior type exist in northeast and central Norway. Norway had

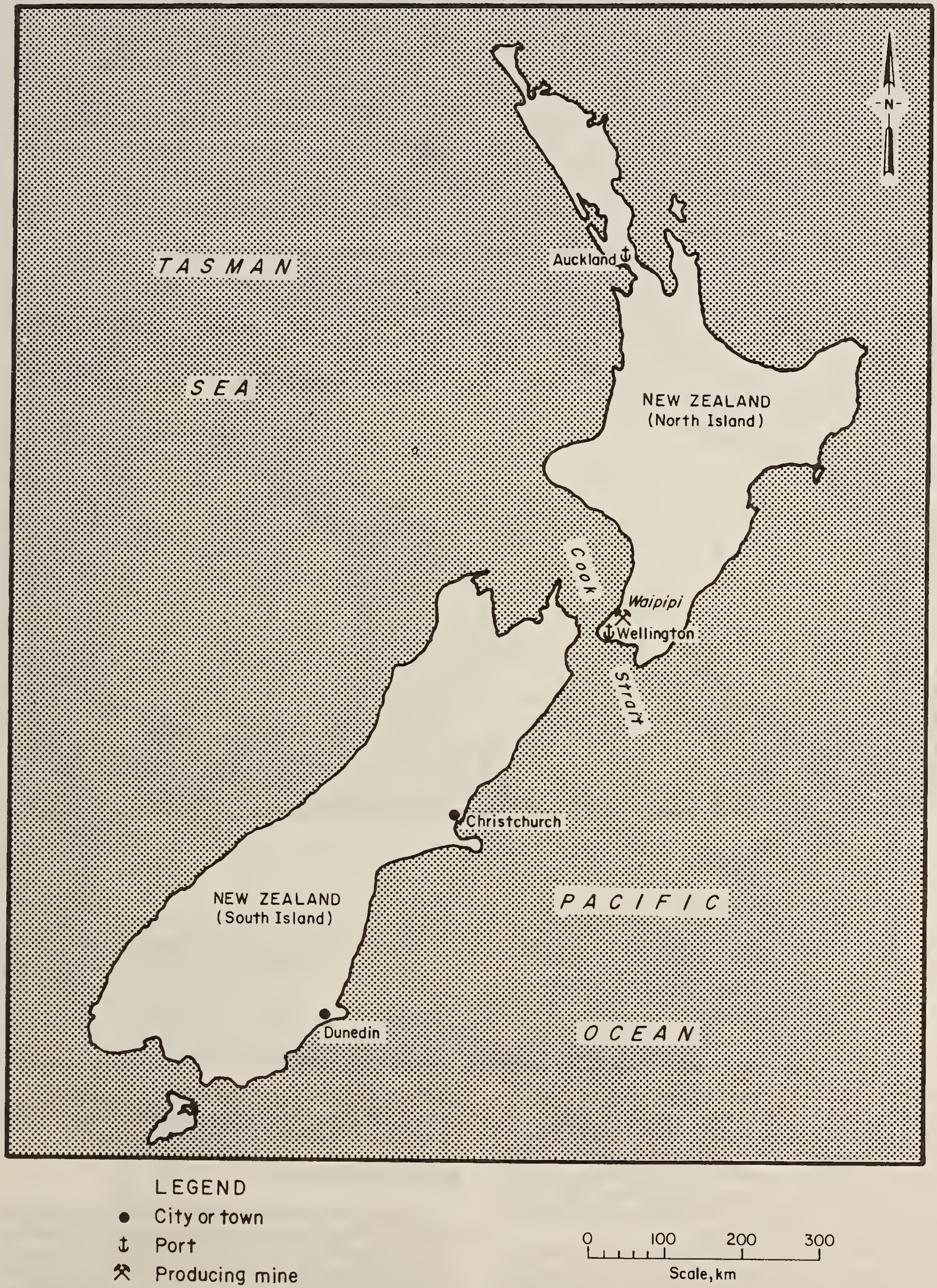

Figure 27.—Location map, New Zealand deposit.

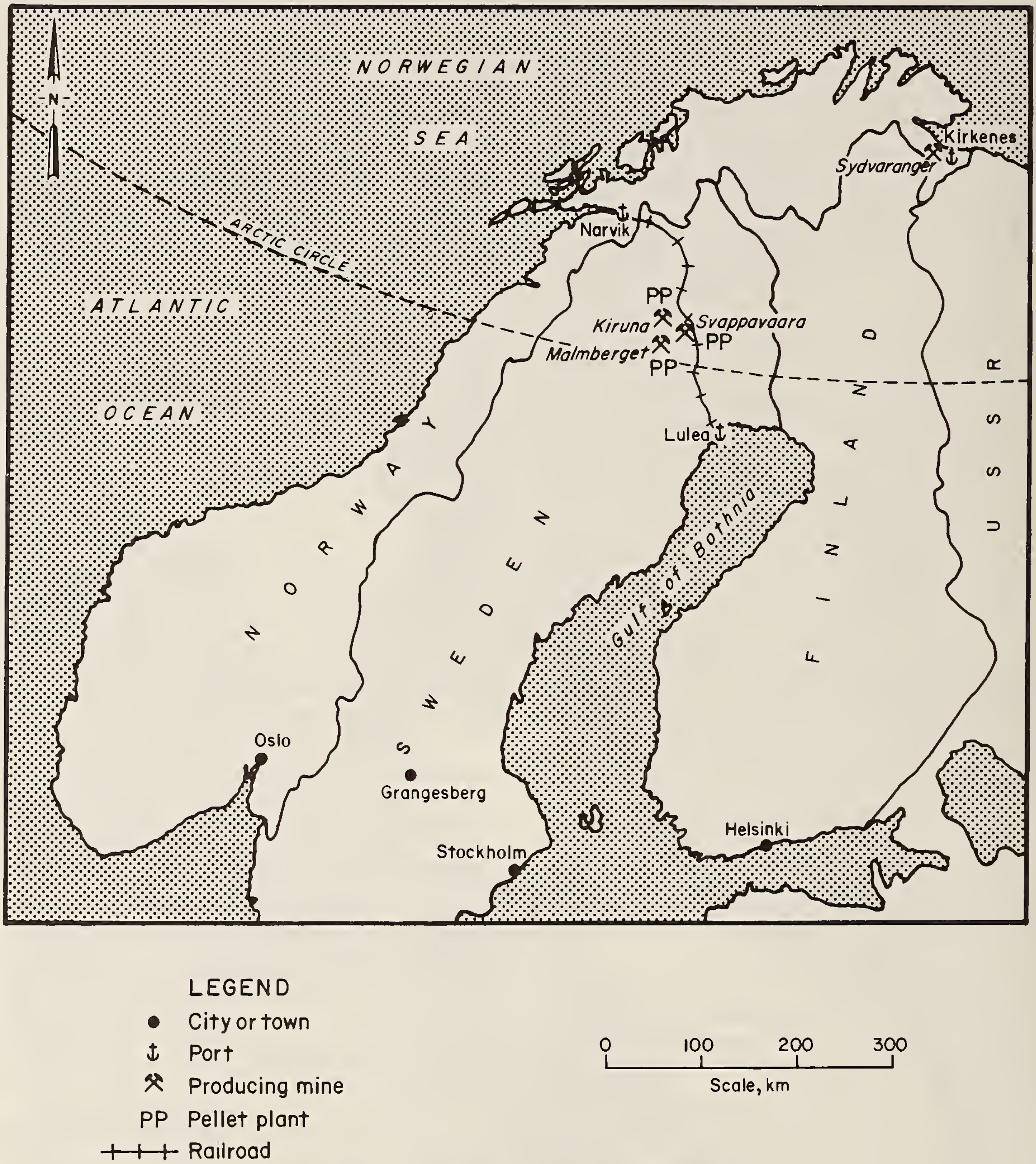

Figure 28.—Location map, Northern European deposits.

a production capacity of about 4 Mmt/yr as of 1982 and contains 400 MMlt of iron resources (*14*). The 150,000-mt/yr Rodsand Mine was closed during 1982. In 1982 Norway's production was about 3.5 Mmt, and exports totaled 2.2 Mmt. Production was evenly divided between pellets (1.8 Mmt) and concentrates (1.7 Mmt). Sydvaranger, the only Norwegian mine evaluated, contains over 187 MMlt of demonstrated iron ore resources.

During the 10-yr period 1973-82, Norway's production of iron ore, iron ore concentrates, and iron ore agglomerates averaged 3.7 Mmt/yr. Norway's exports of iron ore during 1980-82 averaged over 75 pct of its total production; the main customers are the Federal Republic of Germany and the United Kingdom, with about 40 pct each.

Spain and Portugal

The iron ore resources of Spain are estimated near 750 Mmt (*14*). Spain has produced an average of 8.2 MMlt/yr of iron ore products for the past 10 yr. The primary producing mine has been the Marquesado, owned by Cia. Andalusa de Minas S.A. (CAM). The mine is an open pit containing

130 Mmt of geological reserves averaging 55 pct Fe with 45 Mmt designated as mining reserves. The Marquesado property had almost 34 MMlt of demonstrated resources included in this study, with a capacity of 3.5 Mmt/yr. The mine has produced an average of 2.7 Mmt/yr of iron ore since 1971, representing about 35 pct of Spain's entire production on an annual basis. Sinter fines comprise about 95 pct of the production, with lump ore making up the balance. The other major producers in Spain are Cia. Minera de Sierra Menana and Altos Hornos de Vizcaya S.A. The locations of Spanish and Portuguese deposits evaluated in the study are shown in figure 29.

Spain exported 23 pct of its iron ore production in 1980 and 13 pct in 1981. The primary destinations for its products were the Netherlands, the Federal Republic of Germany, and Romania. In contrast, the rapid increase in both output and domestic consumption of steel has made Spain a net importer of iron ore, and in 1980 and 1981 imports amounted to 4.8 and 4.7 Mmt, respectively. Main suppliers were Brazil, Venezuela, and Liberia.

The age and low capacity of port facilities at Almeria, built in 1914, have played a major role in keeping production capacity of CAM down. This situation, coupled with a 100-km rail transportation route through mountainous

Figure 29.—Location map, Spanish and Portuguese deposits.

country with severe gradients and curves, has been a very limiting factor. However, port facilities have been improved and new loading equipment makes it possible to handle vessels up to 90,000 DWT. Therefore, the throttling effect of inadequate port facilities is no longer a factor in limiting production from the Marquesado Mine. It is now conceivable that a production rate of 4 to 5 Mmt/yr is possible with the construction of additional treatment facilities to cope with quality fluctuations in the ore deposit.

Portugal has rather limited resources of iron ore, when placed in context with other major iron ore producing countries in Europe, with reserves of 600 Mmt and a mean iron content of 37 pct Fe (*14*). The Moncorvo deposit is the largest and has measured reserves of 200 Mmt with another 500 Mmt of inferred ore. Over 240 MMlt of demonstrated resources at 37 pct Fe were evaluated. Development of this deposit has been considered by the Portuguese Government for at least 10 yr but has recently been slowed by a lack of markets and beneficiation problems. Construction of a major rail line, connecting the deposit to the rest of the country, has been deferred. Along with infrastructure problems the high phosphorus content of the ore presents beneficiation problems that may preclude the production of an internationally marketable concentrate or iron ore pellet. The Moncorvo deposit has a potential production capacity of 4 Mmt/yr pending resolution of the aforementioned problems. Over the period 1974-82 Portugal produced an average of 54,000 mt/yr of iron ore. Imports of iron ore were 495,000 and 524,000 mt in 1980 and 1981, respectively, and came from Africa and Venezuela.

Africa

Africa has an estimated 14.6 billion lt of iron ore in its reserve base with over 7.6 billion lt of contained iron (*1*). This relatively low figure for such a large continent is attributable to the fact that many areas in Africa have not been thoroughly explored for iron ore and are therefore credited with low reserves.

In this availability study, 19 deposits (7 producing and 12 nonproducing) with demonstrated resources totaling over 8.0 billion lt Fe in 11 African countries were investigated. Many of these countries are considered underdeveloped, and rail transportation and infrastructure development would open up the country to commerce and trade not only in iron ore but for other commodities as well. In some instances, particularly Liberia and Mauritania, iron ore is the main source of revenue for the country.

The African iron ore mines and deposits are predominantly sources of sinter fines. As illustrated in figure 19, nearly 3.9 billion lt of sinter fines are potentially available, accounting for approximately 20 pct of the 18.6 billion lt of sinter fines available in MEC's.

Of the 17 African properties evaluated, 8 are currently producing sinter fines and 9 are potential producers of sinter fines. The producers account for approximately 966 MMlt (24 pct) of sinter fines potentially available at a 15-pct DCFROR, all for less than $0.40 per iron unit, f.o.b. port. The nonproducers account for the remaining 2,980 MMlt (76 pct), which are available at a 15-pct DCFROR within a total cost range of $0.30 to $0.79 per iron unit, f.o.b. port.

The 1984 prices for sinter fines from the Republic of South Africa to Europe ranged from $0.21 to $0.24 per iron unit, f.o.b. port, while from Mauritania and Liberia prices to Europe were $0.28 per iron unit, f.o.b. port. It should be noted that the South African prices were from spot fixtures and included some demerits for high alkali. Given these market prices, potentially 186 MMlt of sinter fines are available for less than $0.28 per iron unit, f.o.b. port, in Africa from three producing properties.

The market price for sinter fines from the Republic of South Africa to Japan in 1984 was approximately $0.24 per iron unit, f.o.b. port, while from Liberia it was around $0.22 per iron unit, f.o.b. port. Approximately 141 MMlt of sinter fines are potentially available at less than $0.24 per iron unit.

Because of the small number of African properties evaluated in the study that produce lump ore and to ensure confidentiality, a curve for lump ore is not shown. Three mines in three African countries contain a total of 911 MMlt of lump ore potentially available, which accounts for 19 pct of the total lump ore potentially available in MEC's. These range between 597 and 910 MMlt in a total cost range of $0.38 to $0.59 per iron unit, f.o.b. port. Lump ore is potentially available at the Simandou deposit in Guinea and the Faleme Area deposit in Senegal, and is produced at the Sishen Mine in the Republic of South Africa (figs. 30-31).

There are 512 MMlt of pellets potentially available in four African countries from five mines. Pellets are available from two producers and three nonproducers within a total cost range of $0.51 to $1.04 per iron unit, f.o.b. port, at a 15-pct DCFROR.

Pellet feed is currently being produced at only one producing mine, located in Liberia. Other potential sources are the Simandou deposits in Guinea and the Guelbs deposit in Mauritania (fig. 32). Combined, there is a potential availability of 156 MMlt of pellet feed at a 15-pct DCFROR, f.o.b. port, within a total cost range of $0.43 to $0.84 per iron unit. This accounts for approximately 19 pct of the total potential availability of pellet feed in MEC's.

A 1984 market price for pellet feed was $0.28 per iron unit from Kudremukh, India, f.o.b. port. From the analysis in this study, pellet feed in Africa is available at a cost level approximately 35 pct higher than this market price.

African pellet costs are generally higher than for other sources of pellets, with several reasons being paramount: higher infrastructure costs involved with railroad and port construction; the higher cost of pelletizing hematite ores; individual country economics; and the fact that state-of-the-art technology in mining and ore treatment processes is not as well developed as in most of the industrialized nations.

Liberia

Liberia has extensive resources of iron ore and ranks second to the Republic of South Africa in production of iron ore. Known reserves are reported at 1.6 billion lt containing about 45 pct Fe. For this study, nearly 1.7 billion lt of demonstrated resources were evaluated from six mines and deposits in Liberia. It is very likely that resources are much greater than have been identified.

All of Liberia's production of iron ore is exported because the country has no iron or steel production. Iron ore continues to be the major export commodity, and in 1982 accounted for about 50 pct of all its exports. Liberia has produced an average of 19.1 MMlt/yr for the 10-yr period 1974-83, although in the last few years production was lower owing to the worldwide recession.

With the mounting financial difficulties of the Liberian mines, the likelihood for expansion of existing mining operations appears slim. The two nonproducing properties, Bea Mountain and Wologisi, contain about 933 MMlt of demonstrated resource averaging 34 pct Fe. These two properties are possible locations for opening new mines when

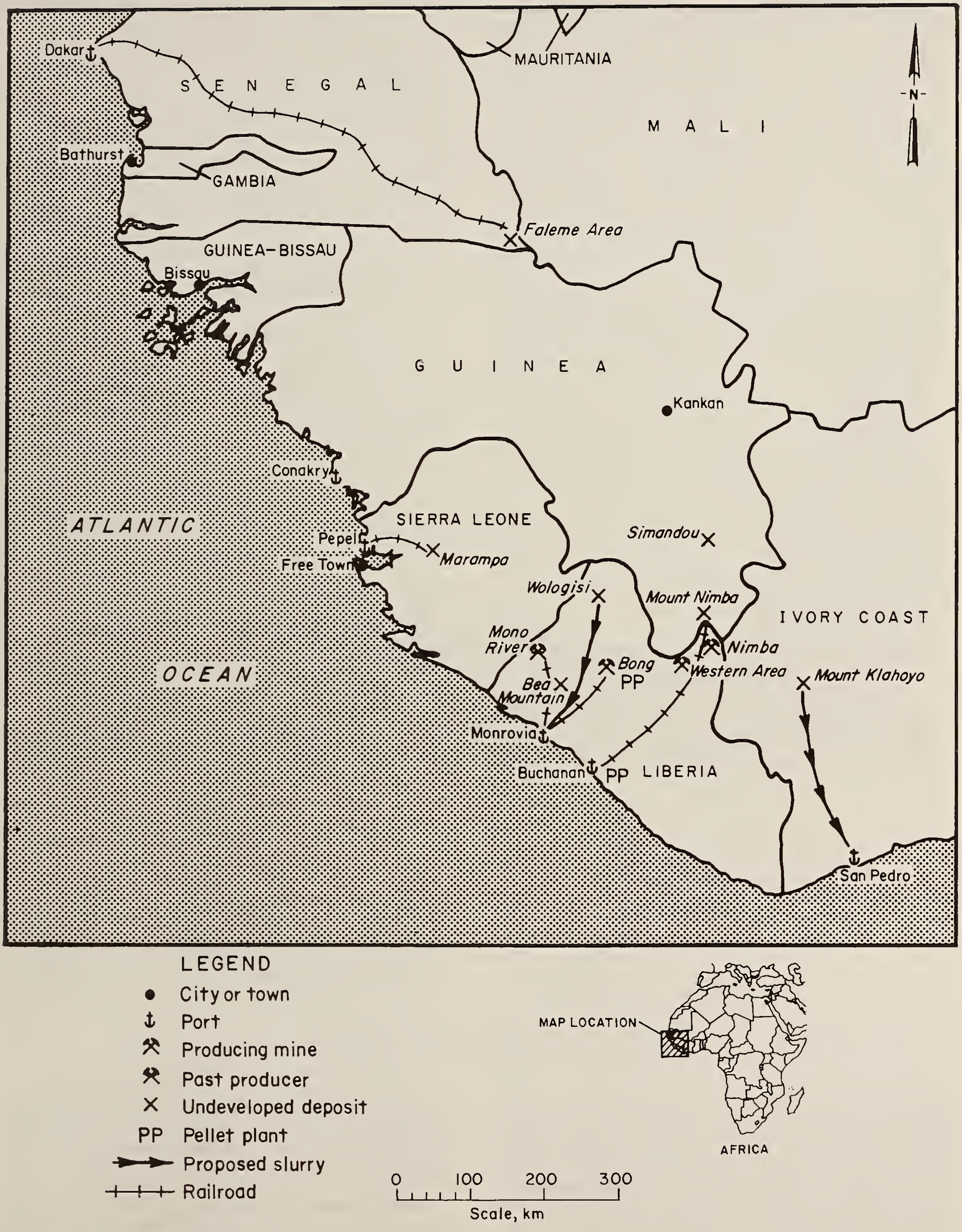

Figure 30.—Location map, Western African deposits.

Figure 31.—Location map, South African deposits.

market and financial conditions are satisfactory. In 1982, engineering and management contracts were signed to begin development of the high-grade Mifergui-Nimba project in neighboring Guinea. This deposit is an extension of the Mount Nimba deposit currently being worked by the Liberian American-Swedish Minerals Co. (LAMCO) at Mount Nimba, Liberia. Owing to the distance from any port in Guinea, the Mifergui-Nimba project was found to be uneconomical unless existing rail and port facilities in Liberia could be used. The geology, mining, and beneficiation processes would all be the same as Mount Nimba, making the development of this project all the more attractive. This project has the potential to produce 15 Mmt/yr of high-grade iron ore. The locations of the west African deposits evaluated in this study are shown in figure 30.

Another development that was considered was the construction of a 105-km rail linkage between the LAMCO railway and the Bong Mining Co. facilities to process LAMCO's Western Area deposit at Bong. A later EEC study, however, found the cost to be prohibitive.

Republic of South Africa

Since 1977, the Republic of South Africa has emerged as the leading producer of iron ore products in Africa, surpassing Liberia. Known reserves amount to 9.3 billion lt, of which approximately 1.3 billion lt of demonstrated iron ore resources were evaluated. South African iron ore production has averaged 21.3 MMlt/yr for the past 10 yr. The worldwide recession resulted in a decline in production to a low of 16.3 MMlt in 1983, but production rose to 21 MMlt in 1984. Coupled with the slackening demand on a global basis, the South African economic growth rate is slowly leading to a reduced demand for steel.

Earlier plans for exploiting taconite-type deposits in the northern Transvaal and the byproduct magnetite produced by Palabora Mining Co. Ltd. (PMC) are stalled. There were plans to use Palabora magnetite ore in a 600,000-mt/yr pellet plant under construction at Vereeniging.

The major producing mine in the Republic of South Africa is the Sishen Mine, owned and operated by the Government-owned South African Iron and Steel Industrial Corp., Ltd. (Iscor). The mine, with a capacity of 27 Mmt/yr, produces 60 pct lump ore and 40 pct sinter fines, averaging 64 pct Fe. Approximately 70 pct of Sishen's ore is transported 861 km by a company-owned electrified railroad to the port at Saldanha Bay. Domestic industry uses the remaining 30 pct, which is transported 690 km by rail to steelworks at Vandeslylpark and 1,005 km to steelworks at Newcastle. The deposit location is shown in figure 31.

South African exports of iron ore amounted to about 50 pct of its total production in 1980 and 1981. The principal destinations were Japan and the Federal Republic of Germany. The port facilities at Saldanha Bay were built primarily for iron ore exports. Saldanha Bay is the deepest port in Africa and capable of handing vessels up to 350,000 DWT.

Other African Countries

Evaluated demonstrated resources of iron ore in Guinea are contained in two major nonproducing deposits and amount to 935 MMlt, averaging 64 pct Fe. There are plans to develop the high-grade hematite deposit at Nimba in southern Guinea. The project was scheduled to produce about 5 to 10 Mmt/yr of sinter fines. Infrastructure and transport links to Liberian port facilities have been negotiated with Liberia to bring this project on stream, but no firm decisions have been made. The project is owned 50 pct by Guinea and 50 pct by foreign shareholders. All of the production is programmed to be shipped to the foreign shareholders according to their ownership percentage. The majority of the ownership resides in Africa, Europe, and Japan.

The Simandou deposit, owned by the Guinean Government, contains 590 MMlt of demonstrated resources at 63 pct Fe. The deposit is still in an undeveloped status because of problems involved in transporting the ore from the deposit. A 760-km railroad from the deposit to port facilities at Conakry will have to be built. The project, if developed, has the potential to produce 20 Mmt/yr of pellet feed, lump ore, and sinter feed.

Another significant deposit in the country is the Conakry, which has a potential resource of 990 Mmt of 52 pct Fe. This deposit, which has disadvantages due to its nickel and chromium content, was shut down years ago and was not evaluated in this study.

The largest potential Ivory Coast mining project known to date is the iron ore deposit at Mount Klahoyo in the Man region. The deposit contains an estimated 659 Mmt of demonstrated resources of 36 pct Fe. If developed, the project has the potential to produce 12 Mmt/yr of pellets. In addition to the Mount Klahoyo deposit, the Ivory Coast has another 1.7 billion mt of potential iron ore resources.

The lack of basic infrastructure and transportation systems within the country hinders the development of its mineral resources. The Mount Klahoyo project lacks the proper ore transportation system from the deposit site to the port at San Pedro. Two solutions have received detailed consideration: (1) pelletization at the mine site and transportation of the pellets via a 376-km railroad, and (2) transportation of the ore as a slurry through a 330-km pipeline and pelletization at the port. The Government favors construction of a railroad, as it can serve multiple uses, but the recession in the steel industry and the major drop in world iron ore prices have caused a postponement of the railroad construction. There has also been recent consideration given to reducing the size of this project.

Senegal's iron ore deposits are of the Lake Superior type, consisting of high-grade hematite and low-grade magnetite ores. The hematite ore averages 64 pct Fe and the magnetite ore between 35 and 50 pct Fe. Demonstrated resources amount to 335 Mmlt of the high-grade hematite and are located in the Faleme area 700 km southeast of the port of Dakar. In addition, there are a further 150 Mmlt of probable and possible reserves. If financing can be obtained, production from this deposit is tentatively scheduled to begin in the late 1980's at a potential annual rate of 4.8 Mmt of lump ore and 7.2 Mmt of sinter fines. Potential markets for the products are France, the Federal Republic of Germany, and Japan. The project could open up the eastern provinces of the country and make Senegal a significant supplier of high-grade iron ore for about 25 yr.

There are two known deposits of iron ore in Sierra Leone: Marampa, which is an active producer; and the Tonkolili, which is classified as a potential resource, containing an estimated 100 Mmt of magnetite ore at 55 pct Fe. The deposits are located within 80 km of each other. The Marampa deposit has remaining demonstrated resources of 57 Mmlt, consisting of 18 Mmlt of itabirite at 38 pct Fe and 39 Mmlt of recoverable tailings at 27 pct Fe. The Marampa Mine was closed in 1975 owing to adverse market conditions and production problems. Production capacity is 1.0 Mmt/yr sinter fines at 65 pct Fe. Prior to closing, Marampa had established export markets for its ore in Japan and Europe. The mine has an estimated life of 28 yr.

The evaluated Algerian iron deposits contain over 1.0 billion lt of demonstrated resources averaging 52 pct Fe. This tonnage, which amounts to almost 7 pct of Africa's iron ore reserve base, is located in two geographical areas—northern Algeria and the Sahara. The huge Gara Djebilet deposit in southwestern Algeria contains about 970 Mmlt at 53 pct Fe. Initial development of this deposit has been started by the recent signing of an $8 million contract with the Soviet Union for technical mining assistance. Large infrastructure expenditures will be required before this deposit will become a producer

Iron ore is currently being mined at the Ouenza property, which has about 40 Mmlt remaining of 53 pct Fe. Total production in Algeria is around 3.5 Mmt/yr with about 1 Mmt/yr being exported. Most of Algeria's exports go to Europe, with about 43 pct of its exports destined to the European Communist bloc countries. The present domestic

Figure 32.—Location map, Northern African deposits.

capacity of 500,000 mt of steel is currently under consideration for expansion to 2 Mmlt by 1987. Completion of this steelmaking expansion program will require Algeria to import iron ore to meet domestic demand until the Gara Djebilet deposit is developed. Locations of the North African deposits evaluated are shown in figure 32.

The Wadi Shatti deposit is Libya's major iron ore resource, with demonstrated resources of 782 million lt. The deposit is mainly magnetite with some siderite at an average grade of 51 pct Fe plus a high phosphorus content. The project has a potential production rate of 10 Mmt/yr sinter fines to be used domestically upon completion of the Misratah iron and steel complex. Misratah, however, will operate at only 3.5 Mmt/yr maximum capacity when completed. Libya currently imports all of its iron and steel requirements, mainly from the Federal Republic of Germany and Italy.

Resources of iron ore in Mauritania consist of Lake Superior-type deposits containing high-grade hematite averaging 65 pct Fe and a low-grade deposit of magnetites-quartzites with 37 pct iron. Total demonstrated resources of 511 MMlt were evaluated from two properties in Mauritania.

Iron ore is the primary export product of the country, accounting for 80 pct of all exports. Over the 10-yr period 1974-83, Mauritania had produced an average of 8.8 Mmt/yr. However, the production in 1982 and 1983 averaged just 7.8 Mmt, owing to the weakness of the iron ore market. Sinter fines is the main product produced, with some lump ore; about 85 pct is exported to Europe and about 15 pct to Japan for sintering at the customer's plants. Production capacity is 9.5 Mmt/yr of sinter fines.

Development work is continuing on the Guelbs magnetite deposit with a scheduled production target of 3 Mmt of iron concentrate suitable for agglomeration and pelletization by 1986, rising to 6.3 Mmt by 1988. A second stage of development is designed to increase output to 9 Mmt by 1992. This project will replace the open pit mines

of the Kedia D'Idjil area, which are scheduled to be phased out by 1990. These deposits have demonstrated resources of 380 Mmlt at 37 pct Fe.

Cameroon's iron ore resources are Precambrian deposits of the Lake Superior type, consisting of hematite and ancillary magnetite. Large amounts of laterite resources grading 50 to 55 pct Fe are also known to exist but have not yet received any meaningful investigation. The locations of deposits evaluated in Cameroon and Gabon are shown in figure 33.

The major deposit having significant commercial potential is Les Mamelles, located in the southwest corner of the country, 10 km inland from the Atlantic Ocean. This property contains all of the country's proven reserves, and demonstrated resources of nearly 197 Mmlt at 30 pct Fe. It has the potential to produce approximately 4 Mmt/yr of pellets if brought into production. All production will be exported, with 75 pct planned for France and 25 pct to other European countries.

The ores in Gabon are of the Lake Superior type and consist mainly of hematite with accessory minerals of goethite and magnetite. The major deposit in Gabon is the Belinga deposit with evaluated demonstrated resources of over 500 Mmlt at 64 pct Fe. The phosphorus content of the ore body is high and requires selective mining. Possible development of this project is dependent on completion of

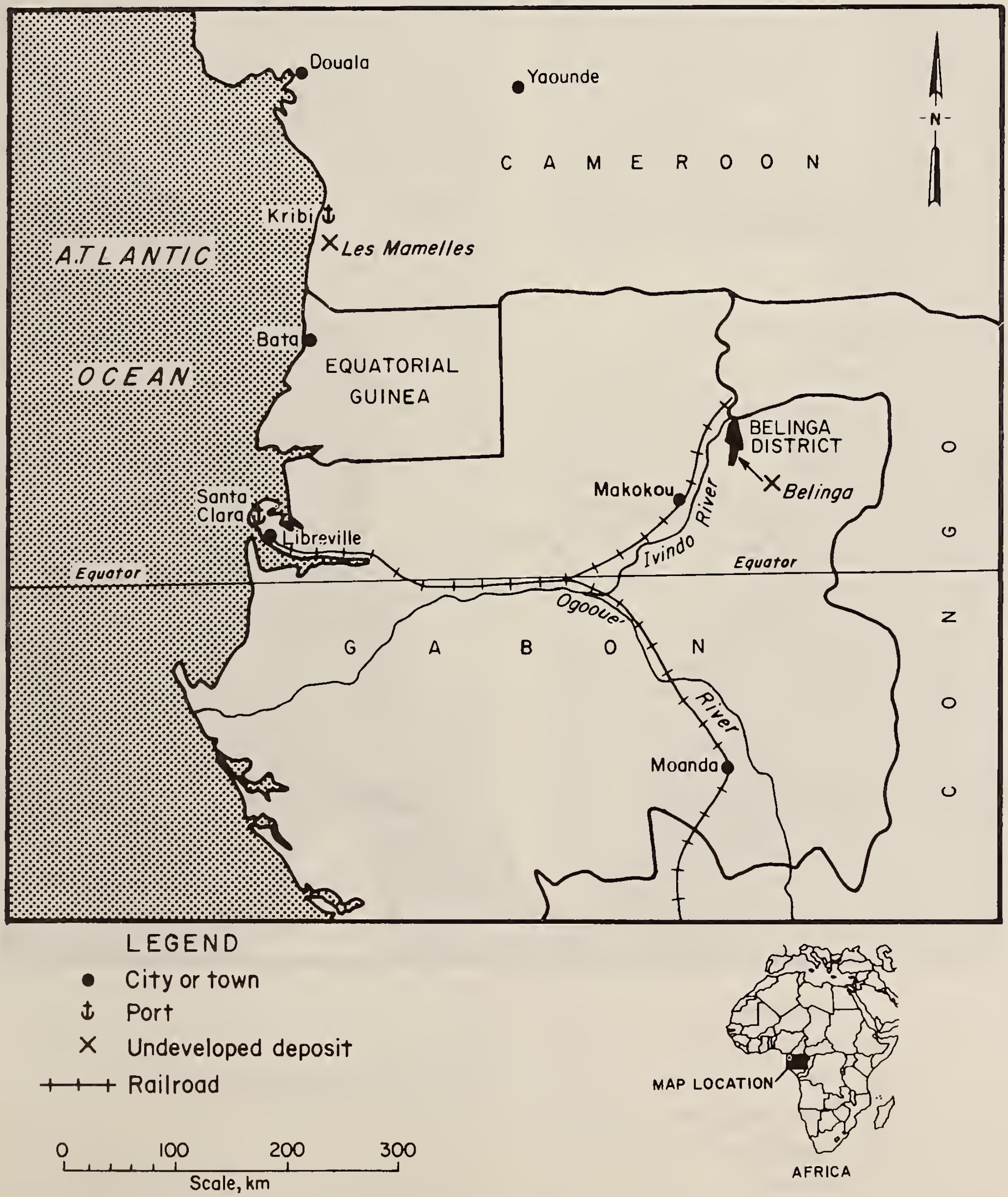

Figure 33.—Location map, central African deposits.

the Trans Gabon railway, which was about 50 pct completed in December 1982. The second portion is scheduled for completion by late 1987.

The project has a potential production rate of 12 Mmt/yr of sinter fines. The product distribution is based on the ownership of the development consortium, which is made up of companies in France, Belgium, and Romania. It is anticipated that all of the production will be exported.

India

India's large reserves of iron ore, amounting to 7.1 billion lt of crude iron ore, represent about 3.4 pct of the world's iron ore reserves. Another 20 billion lt are considered inferred resources. Evaluated in this study were five properties with nearly 1.6 billion lt of demonstrated resources of iron. Iron ore is India's second largest mineral

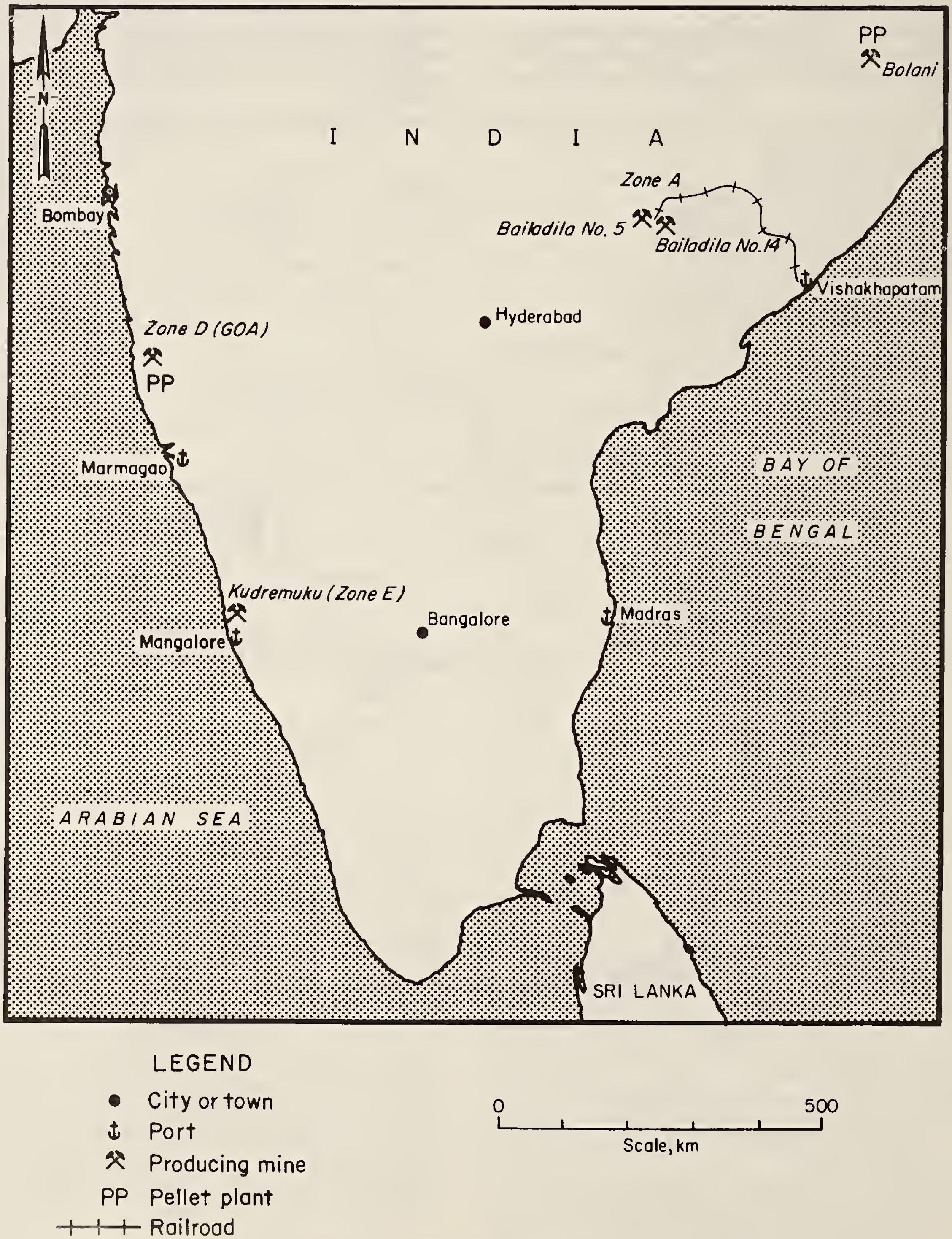

Figure 34.—Location map, Indian deposits.

resource next to coal and lignite. Although capacity exists for producing 54 Mmt/yr of iron ore, output has only been about 40 Mmt/yr. The main producing region is the Goa Territory, followed by the States of Orissa, Bihar, and Karnataka. Locations of the Indian iron ore deposits evaluated are shown in figure 34.

Productivity in the Indian iron ore mining industry is relatively low as an average, although productivity in a few larger mines is higher. The main reason for this is that the industry consists of a large number of smaller production entities that do not lend themselves to large-scale mining and mechanization. Turnover of the work force is minimal despite relatively low wages.

Mechanized mining is a relatively recent development in Indian iron ore production. Manual mining of float ore still persists in some of the smaller, scattered deposits and even exists in conjunction with mechanized operations. Therefore, the mining of large, in-place deposits by mechanized means has become the most important production strategy.

India has major constraints on exports, which include inadequate port and rail facilities and high rail freight charges. Transportation problems have been the major hindrances in the expansion of Indian iron ore trade. Inadequate port facilities with shallow water depths and obsolete stockpiling, reclaiming, and loading capabilities have prevented the utilization of large-capacity ore carriers. Railway development and expansion have lagged behind the development of the mineral industry in general and the iron ore industry in particular. Truck haulage of mineral commodities is limited to short distance transport by poor road conditions, which are exacerbated during the monsoon season and by the inadequate number of trucks available. Planned port dredging and expansion programs should ameliorate the shipping bottleneck somewhat, and slurry pipeline and conveyor systems will deliver the product to railheads and ports more efficiently.

India is a major exporter of iron ore, with Japan, Romania, and the Republic of Korea being the major customers. About 60 pct of India's current production is destined for the export market, with the balance consumed by the domestic iron and steel industry.

India's newest iron ore mine was completed in 1980 at Kudremukh. This project is one of the larger new iron projects worldwide during the past decade. Kudremukh has the capacity to produce high-grade concentrate at the rate of 7.5 Mmt/yr, which could make it the largest single iron ore producer in India. Capacity production, though not likely for some time, may expand India's iron ore exports by about 25 pct to 30 Mmt/yr.

Availability curves for Indian iron ore products are not shown in order to prevent disclosing confidential information due to the small number of properties involved. At a 15-pct DCFROR, between 15 and 270 Mmlt of sinter fines is potentially available within a total cost range of $0.22 to $0.31 per iron unit, f.o.b. port, from four of the five evaluated Indian properties.

Some 1984 Japanese market prices for sinter fines from India ranged from $0.25 to $0.27 per iron unit, f.o.b. port. Approximately 213 Mmlt (79 pct) of the total potentially available sinter fines in India are within a total cost range of $0.22 to $0.26 per iron unit, f.o.b. port, at a 15-pct DCFROR.

The potential availability of lump ore from these four properties, within the total cost range of $0.26 to $0.35 per iron unit, is between 50 and 260 Mmlt, f.o.b. port, at a 15-pct DCFROR. All properties are producing operations. Prices for lump ore being marketed to Japan in 1984 ranged from $0.27 to $0.30 per iron unit, f.o.b. port. Approximately 203 Mmlt (78 pct) of the total lump ore is potentially available at less than a total cost of $0.30 per iron unit, f.o.b. port, 15-pct DCFROR.

The Kudremukh Mine, the only evaluated Indian property that produces pellet feed, accounts for approximately 16 pct of the 168 Mmlt of pellet feed potentially available in MEC's. A 1984 market price for pellet feed from Kudremukh was $0.28 per iron unit, f.o.b. Mangalore.

Regional Availability Summary

From the deposits evaluated in this study, a total of 18.6 billion lt of sinter fines, 4.9 billion lt of lump ore, 14.7 billion lt of pellets, and 820 MMlt of pellet feed are potentially available in MEC's. However, the availability of iron ore products is much more important on a regional basis because each product is marketed in specific industrialized regions of the world, thus causing large volumes of international trade. Therefore, the availability of iron ore products can be related to the actual market and market prices.

Table 16 summarizes the availability of the various iron ore products on a regional basis. Listed for each producing region are the iron ore product, the number of producers and nonproducers of that product, the total available tonnage, and the tonnage available at costs equal to or below various reference prices. The availability of each product in each region is listed with reference to prices in two markets: Europe and Japan. For each reference market, reference prices which are equivalent to 1984 market prices are given. The tonnage available at a total cost that is less than or equal to the reference price is then given, illustrating what is potentially available in individual regions.

Table 16.—Summary of availability of iron ore products for selected regions

Region or country	Producers[1]	Nonproducers[1]	Total available tonnage, MMlt	Reference market: Europe — Reference price,[2] $/ltu	Reference market: Europe — Tonnage available at total cost less than or equal to reference price,[3] MMlt, f.o.b.	Reference market: Japan — Reference price,[2] $/ltu	Reference market: Japan — Tonnage available at total cost less than or equal to reference price,[3] MMlt, f.o.b.
Brazil:							
Lump ore	12	2	1,200	NAp	NAp	0.24	825
Sinter fines	13	1	2,700	0.26	1,700	.24	1,600
South America:							
Lump ore[4]	4	5	520	NAp	NAp	.24	280
Sinter fines[5]	5	5	1,300	[6].33	225	.21	225
Pellet feed[7]	5	6	480	NAp	NAp	.28	208
Pellets[8]	7	2	1,000	.34–.36	[9]442	NAp	NAp
Africa:							
Lump ore	1	2	910	NAp	W	NAp	W
Sinter fines	8	9	3,900	.28	186	.22	[10]141
Pellet feed	1	2	160	NAp	W	.28	W
Pellets	2	3	510	NAp	W	NAp	W
India:							
Lump ore	4	0	260	NAp	NAp	.27–.30	[11]203
Sinter fines	4	0	270	NAp	NAp	.25–.27	213
Europe:							
Pellets	4	0	490	.38	W	NAp	NAp
Lump ore	2	0	540	NAp	NAp	NAp	NAp
Australia:							
Lump ore	3	3	1,400	[6].36	1,100	.31	1,300
Sinter fines	5	12	8,500	[6].33	1,400	.26	2,600
Canada: Pellets	3	0	930	.28	W	NAp	NAp
United States: Pellets	11	30	11,400	[12].80–.86	[13]2,100	NAp	NAp

W Withheld. NAp Not applicable.
[1]Individual properties may produce more than 1 product.
[2]Reference price is equivalent to various 1984 market prices for European or Japanese markets.
[3]Total cost is determined at a 15-pct DCFROR.
[4]Includes Venezuela and Chile.
[5]Includes Chile, Peru, and Venezuela.
[6]c&f price.
[7]Includes Brazil, Peru, and Venezuela.
[8]Includes Brazil.
[9]At $0.38/ltu Fe.
[10]At $0.24/ltu Fe.
[11]At $0.30/ltu Fe.
[12]Market is within United States.
[13]At $0.80/ltu Fe.

CONCLUSIONS

The world's iron and steel industry is dependent upon the supply of iron derived from a variety of iron ore deposits. In an effort to appraise the resources of iron ore, the Bureau of Mines evaluated 129 mines and deposits in MEC's. The mines and deposits analyzed included 63 producing mines and 66 nonproducing properties with in situ iron ore tonnage for all properties combined totaling 75.3 billion lt, with 29.8 billion lt of contained iron. The study excluded mines and deposits in China, the U.S.S.R., and other CPEC's.

The study revealed that demonstrated resources of iron ore are more than adequate to satisfy demand well into the next century and that large quantities of demonstrated iron ore resources, particularly in developing countries, are ready to be developed. In areas where geological mapping is well advanced, as in Europe and North America, new discoveries of iron ore that will significantly alter the order of magnitude of current resource data are unlikely. The possibility exists, however, for significant new discoveries in the developing areas of the world that could expand the reserve base.

Four countries—the United States, Australia, Brazil, and Canada—contain 79 pct of the demonstrated resources evaluated in this study. The United States has 49 pct of the total iron ore resources. It should be noted that the high total for the United States is mainly due to the detailed coverage of the deposits, including the magnetic taconites in Minnesota.

From the resources evaluated in this study, annual, total and regional availability of iron ore products was determined, as shown in tables 13, 14, and 16, respectively. Availability of resources producing various iron ore products is given as totals and on an annual basis through the year 2000 at total costs less than or equal to recent market price levels.

Of all the marketable iron ore products potentially available, sinter fines comprise the greatest share, totaling 18.6 billion lt. Of this total, 8.5 billion lt are from Australia, 2.7 billion lt are from Brazil, and 3.9 billion lt are available from Africa. At total costs less than or equal to 1984 market prices, with a range of $0.22 to $0.33 per iron unit, between 2.9 and 10.4 billion lt of sinter fines are potentially available.

Iron ore pellets make up the second largest marketable iron ore product. Approximately 14.7 billion lt are potentially available in the MEC's with 3.3 billion lt from foreign properties and 11.4 billion lt from domestic operations. At total costs less than or equal to the 1984 foreign market price range of $0.34 to $0.38 per iron unit, approximately 350 to 440 MMlt are potentially available in MEC's, excluding the United States. Of the 11.4 billion lt potentially available from domestic deposits, 2.1 to 2.2 billion lt are available at total costs less than or equal to the 1984 U.S. market price range of $0.80 to $0.86 per iron unit.

The total potential availability of lump ore evaluated in this study is 4.9 billion lt. Brazil accounts for 1.2 billion lt of the total, and Australia accounts for 1.4 billion lt. At less than the 1984 market price of $0.26 to $0.32 per iron unit, 2.2 to 3.0 billion lt of lump ore are potentially available.

There are approximately 820 MMlt of pellet feed potentially available in MEC's. Brazil and Venezuela, with a combined 312 MMlt, are the major sources in the MEC's. Approximately 208 MMlt are potentially available at total costs less than a typical 1984 market price of $0.28 per iron unit f.o.b. port.

In the past several years many factors have affected the iron ore industry. Changes in the world economy, high inflation, high labor rates in developed countries, and high energy costs have all affected the costs of beneficiation and transportation, the major components of delivered cost of iron ore products.

This analysis showed that capital cost expenditures for an iron ore mine are large. Estimates of investments for large mines with capacities of 35 to 46 MMmt/yr range from $2.0 billion to $3.4 billion. This is due to large volumes of ore mined and processed, the transport required to move the product, and the necessary infrastructure support.

Operating costs for surface iron ore mining range from $1.00/lt to $5.00/lt. Beneficiation costs range from $3.25/lt to $5.00/lt, depending on types of ore being processed. Pelletizing costs for magnetite ores range from $6.00/lt to $12.80/lt in various regions; hematite ore processing costs range from $15.00/lt to $22.70/lt. Pelletizing is very fuel intensive, and costs are heavily influenced by rising or falling fuel prices. Price changes for oil or natural gas will have a corresponding positive or negative effect on the world's pelletizing industry. The possibility of higher fuel prices led to developments within the industry to reduce energy consumption in the pelletizing process.

Similarly, fuel fluctuations can affect the cost of transporting iron ore. Rail rates vary by distance transported and country, while ocean shipping rates vary by distance shipped and size of vessel. Ocean shipping costs can account for up to 70 pct of the final cost of the iron ore product. Changes in the ocean shipping industry have had a singular impact on the iron ore picture in recent decades. The construction and use of large vessels of up to 280,000 DWT and the construction of ports capable of berthing and loading these vessels have made many areas previously regarded as too far from markets now major economic sources of iron ore. Despite rising fuel prices of the early 1980's, ocean freight rates have declined owing to the fierce competition in shipping commerce and low demand for iron ore.

Compounding these problems for the U.S. iron ore industry have been the added effects of the decline in domestic steel demand and continuing imports of large amounts of foreign steel. Since the domestic iron ore industry is directly linked to the U.S. steel industry, there is a general consensus that the continuing contraction of the U.S. steel industry, due partly to increasing imports of foreign steel, will have an adverse effect on the domestic iron ore industry.

In summary, the iron ore industries of the world have substantial resources of iron ore to satisfy the demand for many years into the future. The revitalization of the iron ore industry, on the domestic scene, will be directly linked to the fate of the U.S. steel industry. However, with the recent declines in the inflation rate and in energy costs, the general outlook for the world iron ore industry may become somewhat more encouraging than in the past few years.

REFERENCES

1. Klinger, F. L. Iron Ore. Sec. in BuMines Mineral Commodity Summaries 1986, pp. 78-79.
2. ______. Iron Ore. Ch. in Mineral Facts and Problems, 1985 Edition. BuMines B 675, 1985, pp. 385-403.
3. Skillings, D. N., Jr. 16th Annual Conference of the International Iron and Steel Institute. Skillings Min. Rev., v. 71, No. 46, 1982, pp. 8-15.
4. The TEX Report, Ltd. Iron Ore Manual, 1982-83. Tokyo, Japan, 331 pp.
5. United Nations Industrial Development Organization. Mineral Processing In Developing Countries. New York, 1980, pp. 27-37.
6. World Bank. Price Prospects for Major Primary Commodities. Volume IV: Metals and Minerals. Rep. 814/84, 1984, pp. 119-184.
7. Cargo Systems Research Consultants Ltd. Iron Ore Ports and Terminals. Ch. in Large Bulk Carrier Ports and Terminals. Worcester Park, United Kingdom, 1981, pp. 19-34.
8. von Wahl, S. Investment Appraisal and Economic Evaluation of Mining Enterprise. Trans Tech Publ., Ser. on Min. Eng., v. 4, 1983, pp. 146-148.
9. Acharya, S. N. Iron Ore—Its Supply, Market Structure and Contractural Arrangements. U.N. Ind. Dev. Org., Jan. 4, 1982, 43 pp.
10. Straam Engineers, Inc. Capital and Operating Cost Estimating System Handbook—Mining and Beneficiation of Metallic and Nonmetallic Minerals Except Fossil Fuels in the United States and Canada (contract JO255026). BuMines OFR 10-78, 1977, 382 pp.
11. Davidoff, R. L. Supply Analysis Model (SAM): A Minerals Availability System Methodology. BuMines IC 8820, 1980, 45 pp.
12. Marsden, R. W. Estimation and Evaluation of the Iron Ore Reserves of the United States—A Partial Survey 1974-75 (contract JO188074, Univ. MN—Duluth). BuMines OFR 109-80, 1980, p. 12; NTIS PB 80-228984.
13. Klinger, F. L. Iron Ore. Ch. in BuMines Minerals Yearbook 1983, v. 1, pp. 447-469.
14. Zitzmann, A. (ed.). Iron Ore Deposits of Europe. Fed. Inst. Geosci. and Nat. Resour., v. 1, 1977, 418 pp.

BIBLIOGRAPHY

American Iron Ore Association. Iron Ore. 1983, 108 pp.

American Mining Congress Journal. International Lending Policies and Their Effect Upon the Minerals and Metals Industry. V. 69, No. 13, July 7, 1983, pp. 10-11.

Bilhorn, W. W., R. E. Sargent, R. M. Whelan, and D. C. Blackwell. Production in DRI—Added Demand for Iron Ore Pellets. Skillings Min. Rev., v. 71, No. 4, 1982, pp. 8-11.

Dastur, S., C. Dasgupta, R. Parthasarathy, and D. S. Baso. Pelletization of Iron Ores in Developing Countries—Present and Future. Paper in Agglomeration 77 (Proc. 2d Int. Symp. on Agglomeration, Atlanta, GA, Mar. 6-10, 1977). AIME, 1977, pp. 74-93.

Engineering and Mining Journal. Japan Uses TiO_2 as Sinter Feed. V. 177, No. 3, 1976, p. 246.

English, A., and R. D. Frans. Developments in Pelletizing. Paper in Agglomeration 77 (proc. 2d Int. Symp. on Agglomeration, Atlanta, GA, Mar. 6-10, 1977). AIME, 1977, pp. 3-22.

Gilchrist, J. D. Extraction Metallurgy. Pergamon, 1st ed., 1966, pp. 30-45; 2d ed., 1980, pp. 96-103.

Greenwalt, R. B., and J. G. Stephenson. The Role of Agglomeration in Direct Reduction Processes. Paper in Agglomeration 77 (proc. 2d Int. Symp. on Agglomeration, Atlanta, GA, Mar. 6-10, 1977). AIME, 1977, pp. 765-783.

Guider, J. W. Iron Ore Beneficiation—Key to Modern Steelmaking. Min. Eng. (NY), v. 33, 1981, pp. 410-431.

Hargreaves, D., and S. Fromson. Iron. Ch. in World Index of Strategic Minerals. Gower Publ. Co., Ltd., 1983, pp. 85-88.

Hedberg, B. The Changing Pattern of the World Iron Ore Supply. Skillings Min. Rev., v. 67, No. 20, 1978, pp. 10-13.

Hedberg, B., and M. Kallin. Future Iron Ore Mining—A Matter of Scale? Skillings Min. Rev., v. 69, No. 42, 1980, pp. 12-13.

Humphrey, G. M. II. World Iron Ore Supply and Demand. Ch. in Minerals Resources of the Pacific Rim, ed. by T. M. Li, G. R. Brown, and N. E. Guernsey. AIME, 1982, pp. 201-204.

Jensen, M. L., and A. M. Bateman. Iron. Sec. in Economic Mineral Deposits. Wiley, 3d ed., 1981, pp. 386-411.

Kammer, C. M. The Great Lakes: A Vital Link for the Nation's Iron Ore Mines and Mills. Min. Eng. (NY), v. 34, 1982, pp. 1441-1443.

Klemic, H. Iron Ore Deposits of the United States of America, Puerto Rico, Mexico and Central America. Ch. in Survey of World Iron Ore Resources. United Nations, New York, 1970, pp. 413-441.

Klemic, H., and M. Cooper. Iron Ore Resources of South America and Their Utilization. U.S. Geol. Surv. Open File Rep. 77-745, 1977, 191 pp.

Klemic, H., H. L. James, and G. D. Eberlein. Iron. Ch. in United States Mineral Resources. U.S. Geol. Surv. Prof. Paper 820, 1973, pp. 291-306.

Klinger, F. L. Iron Ore. BuMines Mineral Commodity Profile, 1978, 27 pp.

______. Iron Ore. BuMines Mineral Commodity Profile, 1983, pp. 76-77.

Lawson-Reid, J. Freights—A Little Sign of Freight Rate Revival in Autumn. Ind. Miner. (London), No. 192, 1983, pp. 73-74.

Lloyd's of London Press. Ports of the World. London, 1982, 750 pp.

Makowski, J. Iron Ore Trade—Trends and Prospects. Skillings Min. Rev., v. 72, No. 2, 1983, pp. 6-16.

McInnes, R. Status and Future of Lake Superior Iron Ore Industry. Skillings Min. Rev., v. 73, No. 17, 1984, pp. 6-9.

Mining Engineering (New York). Despite Slight Steel Recovery, Iron Ore Problems To Remain. V. 35, 1983, p. 302.

Morgan, J. Mining's Comeback Is Slow and Uneven, But There Is Improvement. Min. Eng. (NY), v. 36, 1984, pp. 461-473.

Moss, P. C. World Iron Ore Supply. Skillings Min. Rev., v. 72, No. 23, 1983, pp. 4-6.

Nilson, D. World Merchant Fleets Development. Skillings Min. Rev., v. 69, No. 49, 1980, pp. 10-13.

Nilson, D., and K. Burgher. Energy Consumption in Hypothetical Medium Size Open Pit. Skillings Min. Rev., v. 70, No. 49, 1981, pp. 10-18.

Ohle, E. L. Evaluation of Iron Ore Deposits. Econ. Geol. and Bull. Soc. Econ. Geol., v. 67, 1972, pp. 953-964.

Peterson, E. C. Iron Ores. Ch. in Mineral Facts and Problems, 1980 Edition. BuMines B 671, 1981, pp. 433-453.

Pietsch, W. Agglomeration and Direct Reduction: A Technical Symbiosis. Min. Eng. (NY), v. 30, 1978, pp. 414-421.

Pomerene, J. B. Geology and Ore Deposits of the Belo Horizonte, Ibirite and Macacos Quadrangles, Minas Gerais, Brazil. U.S. Geol. Survey Prof. Paper 341-D, 1964, 81 pp.

Reno, H. T., and F. E. Brantley. Iron, A Materials Survey. BuMines IC 8574, 1973, 117 pp.

Roe, L. A. Iron Ore Beneficiation. Min. Publ. Co., Lake Bluff, IL, 1957, 305 pp.

Sasadi, J. Latest Developments in Coal Handling for Self-Unloading Ships and Barges. Bulk Solids Handling, v. 2, No. 3, 1982, pp. 383-396.

Skillings, D. N., Jr. International Iron Ore Symposium. Skillings Min. Rev., v. 70, No. 18, 1981, pp. 12-18.

______. Third International Iron Ore Symposium. Skillings Min. Rev., v. 72, No. 15, 1983, pp. 6-11.

Skillings Mining Review. Canadian Iron Ore Industry. V. 71, No. 8, 1982, pp. 8-9.

Szabo, P. J. International Aspects of Minerals Transportation; Iron Ore, Coal and Phosphate. Min. Eng. (NY), v. 34, 1982, pp. 1460-1462.

Thomas, N. G. Iron Ore in the 80's. CIM Bull., v. 74, No. 825, 1981, pp. 149-154.

United Nations. Survey of World Iron Ore Resources. New York, 1970, 479 pp.

______. The Maritime Transportation of Iron Ore. New York, 1974, 95 pp.

______. The World Market for Iron Ore. New York, 1968, 479 pp.

Wall Street Journal (NY). Steelmakers' Excess Ore Capacity Hindering the Industry's Recovery. Aug. 29, 1983, p. 13.

Wens, H. G., and K. O. Weil. The Iron Ore Industry in the Main EEC-Supplier Countries. Gluckauf (Engl. transl.), v. 119, No. 6, 1983, pp. 100-105.

Wills, B. A. Mineral Processing Technology. Pergamon, 2d ed., 1981, pp. 188-189.

World Mining. Future Prospects for the Direct Reduction of Iron. V. 32, No. 5, 1979, p. 44.

______. Peru. Sec. in Newsmakers in World Mining. V. 34, No. 7, 1981, p. 58.